

## **A manager's guide to optimising furnace performance**



*ENERGY EFFICIENCY*

**BEST PRACTICE  
PROGRAMME**

# A MANAGER'S GUIDE TO OPTIMISING FURNACE PERFORMANCE

This Guide is No. 253 in the Good Practice Guide series and is intended to help managers in the operation of high temperature furnaces and kilns. Furnace operation is a costly and complex business, and getting it right is important if product quality, throughput and profitability are to be maintained.

Extensive experience working with furnace users has shown that operating cost savings of 10-30% can often be achieved with little or no capital outlay. To achieve this managers must recognise that getting the most from a furnace is not just a technical issue – there are many management issues too.

The problem for busy managers is knowing where to start – this Guide explains where and how to start saving money.

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## LIST OF RELEVANT GOOD PRACTICE GUIDES

These and other relevant publications are listed on the fax-back form at the back of this Guide.

Copies of these Guides may be obtained from:

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## **FOREWORD**

This Guide is part of a series produced by the Government under the Energy Efficiency Best Practice Programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

- *Energy Consumption Guides*: (blue) energy consumption data to enable users to establish their relative energy efficiency performance;
- *Good Practice Guides*: (red) and *Case Studies*: (mustard) independent information on proven energy-saving measures and techniques and what they are achieving;
- *New Practice projects*: (light green) independent monitoring of new energy efficiency measures which do not yet enjoy a wide market;
- *Future Practice R&D support*: (purple) help to develop tomorrow's energy efficiency good practice measures.

If you would like any further information on this document, or on the Energy Efficiency Best Practice Programme, please contact the Environment and Energy Helpline on 0800 585794. Alternatively, you may contact your local service deliverer – see contact details below.

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## **1. INTRODUCTION**

This Guide is intended for busy managers who would like straightforward suggestions for improving the profitability of their furnace operation. It is a practical Guide that suggests how, when and why to make improvements that will result in a more cost-effective operation.

This Guide highlights the key points in an easy to read manner, and shows where to go for further information. At the heart of the Guide are Fact Files; concise sheets that provide information on specific topics, from improving yield, to shopping around for cheaper electricity.

Additional information on most topics can be obtained from the wide range of free publications produced by the Energy Efficiency Best Practice Programme. References are given at the bottom of each Fact File so you can see the publications that will help you the most with any given area of operation.

The Core Guides should be considered as ‘essential reading’ as these cover many topics. Some of the other publications are aimed at specific industry sectors, e.g. ferrous metals, ceramics. However, the information contained within them is often of value to a much wider audience. A fax-back order form is provided at the back of this Guide.

### **1.1 Getting Started**

Many improvements can be made to your furnace operation at little or no cost and these will improve efficiency and save your company money. Applying effective management techniques to get the best possible performance from your existing plant and equipment should be the first step in any planned programme of improvements. The Fact Files addressing management issues appear first in this Guide. Without proper management systems in place, it will be impossible to make informed decisions about future investment in technology to improve furnace efficiency. Technology issues are dealt with in the second set of Fact Files.

To help guide you through the issues involved, are two sets of Key Questions (Sections 1.3 and 1.4). To discover the changes that will have the biggest impact on your operations, work your way through the questions. If there are any that you cannot confidently answer ‘yes’ to, refer to the corresponding Fact File to see what opportunities you may be missing.

Section 2 is a Troubleshooting Guide which shows how the Fact Files can provide help in overcoming common operational problems. The checklist in Section 3 will help you to make the right decisions the next time you come to specify a new furnace.

Take a few seconds to read the following Case Histories that demonstrate how simple changes have saved other companies money – can you afford not to do the same for your company?

## 1.2 Case Histories

### FERROUS METALS SECTOR

#### Demonstrating good practice in medium frequency coreless induction furnaces

Alfer Ltd, a division of the Baxi Partnership, operates a modern iron foundry to mass produce the cast iron heat exchangers used in its range of domestic boilers. A range of castings is also produced for outside customers, mainly in the automotive industry.

Continuous mould production, the use of molten holding and automatic pouring facilities enables operating procedures to provide an outstanding example of good practice in the medium-frequency melting of cast iron. These procedures result in low specific energy consumption (SEC) and energy efficient operation of the melting furnaces.

If the SEC at Alfer could be achieved by all foundries using coreless induction furnaces, an annual energy saving of about 34 million kWh or 120,000 GJ would result in the UK, producing a cost saving of about £1.2 million/year to the industry.

For further information see GPCS 213, *Demonstrating good practice in medium frequency coreless induction furnaces*.



The melting furnace with its lid closed

## NON-FERROUS METALS SECTOR

### Energy savings from small, efficient melting and holding furnaces

Quinton Hazell Automotive Ltd is a member of the UK based Echlin Group and a major supplier of water pumps, steering and suspension parts to the automotive industry.

In 1994, the company converted its electrical induction and melting unit, ladle transfer system and holding furnaces to modern, gas-fired small melting/bale out furnaces. These provide a number of energy benefits including:

- use of a cheaper fuel;
- heat recovery from combustion exhaust gases to preheat the incoming charge;
- improved insulation.

The total investment cost was £112,000, but savings of £69,700/year have resulted, giving a simple payback period of 1.6 years.

For further information see GPCS 344, *Energy savings from small, efficient melting and holding furnaces*.

## CERAMICS SECTOR

### Improved heat distribution in a tunnel kiln

The Yorkshire Brick Company made several types of perforated clay bricks for use in the construction industry. In 1988, one of its gas fired tunnel kilns was modified to improve the temperature distribution in the brick setting.

A hot air recirculation system was added in the early heating stages, extra burners were installed and better control of cooling was implemented. These changes resulted in a faster firing schedule, with product quality maintained.

Substantial energy and cost savings were achieved as a result. The greatest cost advantage came from the increased productivity of the kiln; output rose by 34%, while the specific energy consumption dropped by 25%. The investment cost was £265,000 and savings of £243,300/year were achieved. The simple payback period on investment was therefore 1.1 years.

For further information see NPFP 17, *Improved heat distribution in a tunnel kiln*.



Inside a tunnel kiln

## GLASS SECTOR

### External spray insulation on furnace regenerators

Beatson Clark plc installed additional insulation to the regenerative heat recovery system on one of the company's furnaces at its factory in Rotherham. The insulation, employing a spray technique, proved simple to install and caused no disruption to the running of the plant.

The resulting energy savings of over £24,000/year arose from both improved thermal insulation and sealing of the structure against the entry of cold air. The installed cost was just £10,500 giving a payback period of 23 weeks.

For further information see GPCS 133, *External spray insulation on furnace regenerators*.



'K' furnace regenerator with Inspray

### 1.3 Key *Management Questions*

If your answer is 'no' or 'don't know' to any of these questions, refer to the relevant Fact File.

	Fact File
Do I really know how much my furnace costs to operate?	M1
Do I know how my costs compare with those of my competitors?	M2
Am I buying my fuel as cheaply as possible?	M3
Am I using the most cost effective raw materials?	M4
Is my furnace as productive as it could be?	M5
Are my furnace loading procedures absolutely right?	M6
Do I schedule my furnace operations in the optimum way?	M7
Are standard procedures in place to deal with production delays?	M8
Do my furnace operators always act as they should?	M9
Have I explored all ways of reducing my labour costs?	M10
Do I use the most effective plant maintenance regime?	M11
Do I know how my furnace performed last week, or last month?	M12
Have I considered the environmental constraints affecting my furnace?	M13
Am I confident about justifying capital expenditure on plant improvements?	M14

#### 1.4 Key *Technical* Questions

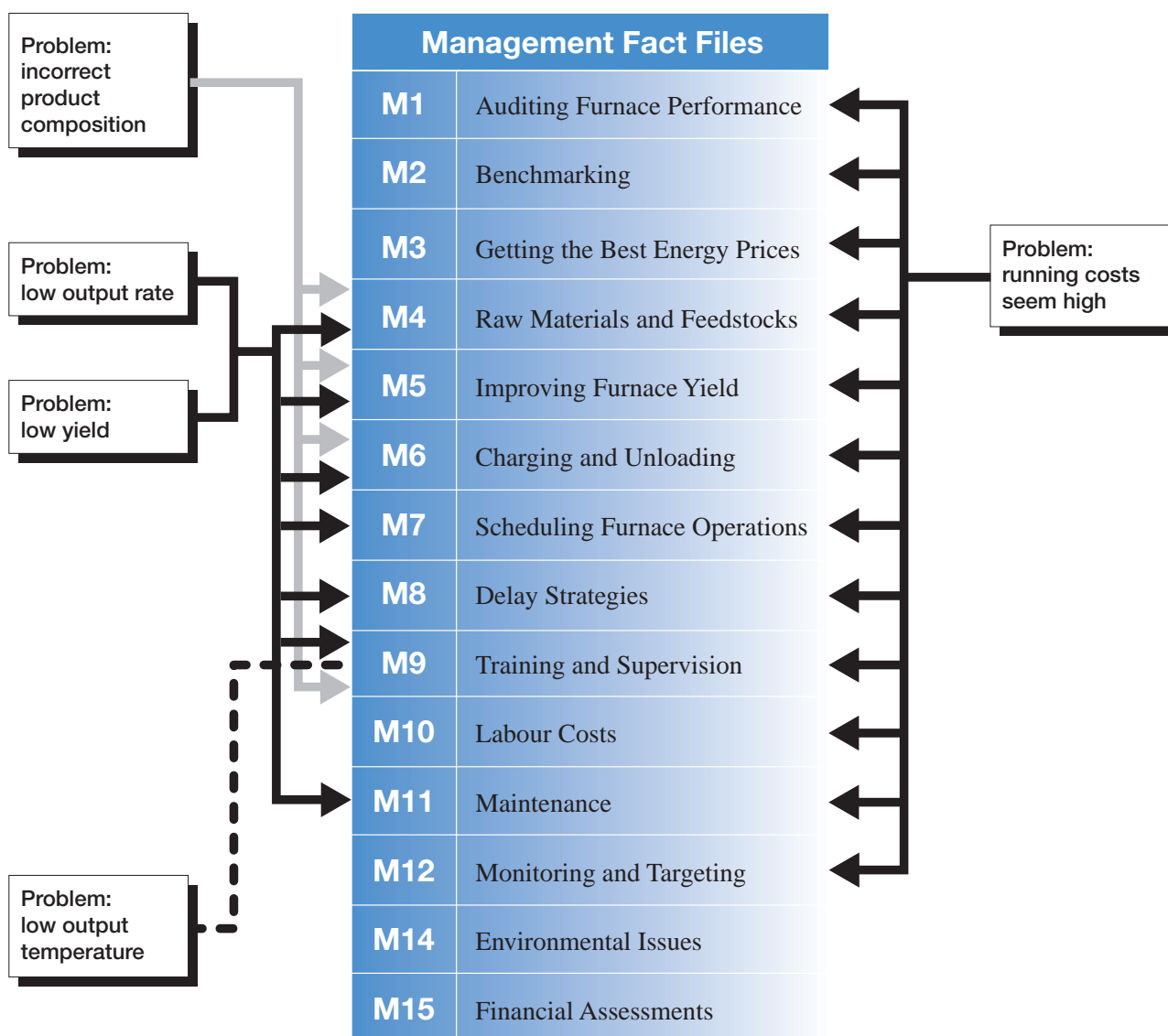
If your answer is 'no' or 'don't know' to any of these questions, refer to the relevant Fact File.

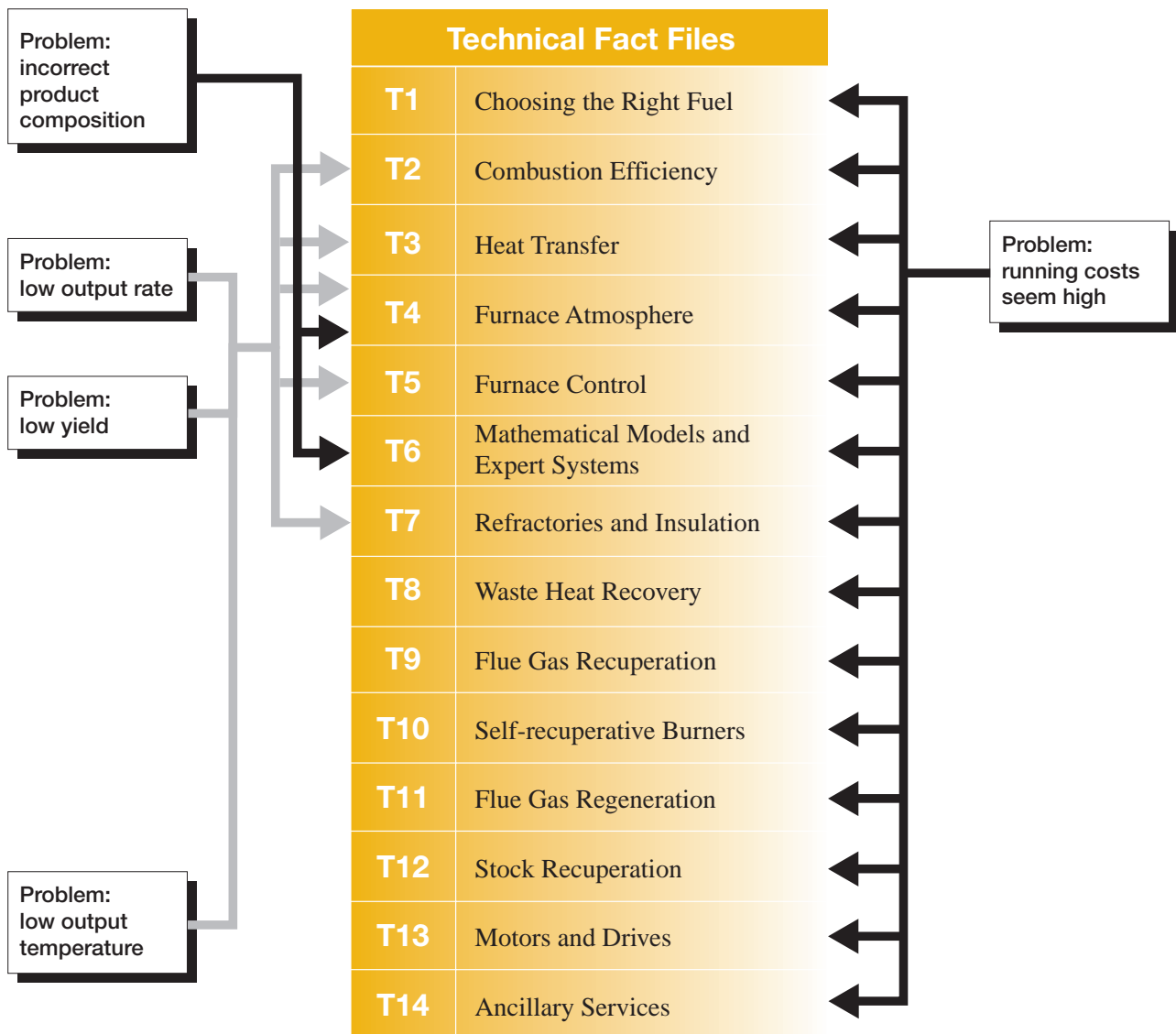
	Fact File
Am I using the right fuel?	T1
Do I get the maximum amount of useful heat from my fuel?	T2
Is heat effectively transferred to stock?	T3
Do I achieve the optimum atmosphere within my furnace?	T4
Are all aspects of my furnace's operation perfectly controlled?	T5
Have I considered using an 'expert system'?	T6
Do I definitely use the right refractories?	T7
Am I recovering and re-using all available waste heat?	T8-T12
Do I use the most efficient motors and drives?	T13
Have I improved the performance of my compressed air and cooling water systems?	T14

## 2. TROUBLESHOOTING GUIDE

The causes and effects of furnace problems are closely bound together, making it sometimes difficult to identify the best action to take. For example, off-spec product could be caused by a number of factors including incorrect raw materials specification, poor heat transfer, inadequate furnace control, etc. Similarly, a single fault, such as inefficient combustion, can result in a multitude of symptoms such as increased fuel usage, reduced yield or off-spec product.

Troubleshooting needs to be approached in a systematic manner. To help you achieve this, use the following diagrams to direct you to the appropriate Fact Files. Work through the referenced Fact Files in order, remembering to address all *Management* issues first, before moving onto the *Technical* ones.





### 3. SPECIFYING A NEW FURNACE CHECKLIST

When specifying a new furnace it is important to consider all options and make informed decisions. Use this quick checklist to help you with your considerations, referring to the relevant Fact File for information.

	Fact File
What flexibility do I need with regard to feedstock specification?	M4
Could I accept a lower specification, cheaper feedstock with a different furnace design?	M4
How will the furnace be best positioned and operated in relation to any upstream or downstream processes?	M5
What is the best way to load and unload the furnace?	M6
What specific training and supervision needs will there be?	M9
Are manning levels minimised?	M10
Are maintenance requirements defined and acceptable?	M11
Does the furnace comply with environmental standards?	M14
Have I considered life cycle costs in making my financial assessment?	M15
Am I using the right fuel?	T1
Is the heat transfer mechanism appropriate for the product?	T2
Is there a requirement for a controlled atmosphere within the furnace?	T4
Are the controls adequate?	T5
Would the furnace justify the use of an 'Expert System'?	T6
Could the refractory specification be improved?	T7
Are there opportunities for waste heat recovery?	T8
Are higher efficiency motors specified?	T13
Are variable speed drives applicable?	T13
Are compressed air and cooling water demands minimised and well controlled?	T14

#### 4. FACT FILES

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Many factors affect furnace performance. The best way of achieving significant improvement is to use a systematic management approach that is grounded in a thorough understanding of the issues involved. This understanding can be developed by auditing the current performance of your furnace in terms of material use, energy use and operating costs. The simplest audit should be undertaken for all furnaces and provides the following basic management information:

- **furnace yield (quantity of useable product per unit of feedstock);**
- **specific energy consumption (energy used per unit of product);**
- **specific production cost (cost per unit of product).**

In addition, most furnaces, particularly those where annual materials, energy, labour or maintenance costs individually exceed £10,000, will benefit from a more detailed audit that will identify the location, magnitude and value of areas of waste.

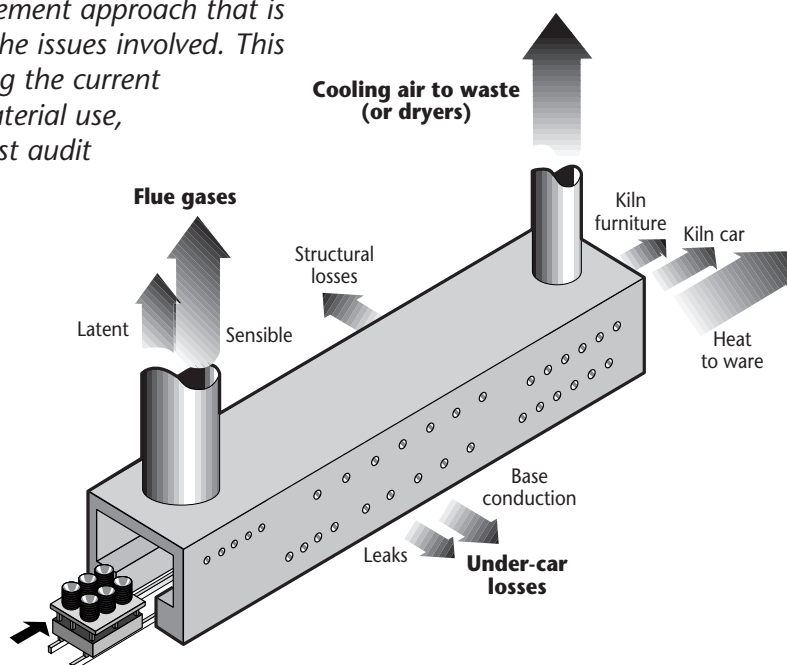


Diagram showing uses and losses of heat in a furnace

The time required to complete the audits may range from a few hours to several days depending on the size and complexity of your furnace. In any case, however, compiling the audits should be viewed as an essential management exercise that will ultimately repay any costs involved many times over.

### KEY POINTS

#### Simple Audits

- Simple audits will generate the three basic performance indicators (furnace yield, specific energy consumption and specific production cost), that will allow you to compare the performance of your furnace with those of others via the use of published benchmarks (see Fact File M2).
- The following data will be required to calculate the performance indicators:
  - a) Weight of feedstock used and usable product produced – this may require production records to be refined, for example, to show the throughput of individual furnaces.
  - b) Amount of energy used – main heating fuel plus electricity used for fans, conveyors etc.
  - c) Operating costs, to include:
    - energy costs;
    - labour costs;
    - raw materials costs;
    - maintenance costs.
- Energy use can initially be estimated from nominal plant ratings (e.g. m<sup>3</sup>/hour of gas, kW of electricity etc.), multiplied by the number of hours run.
- If the estimated annual energy cost exceeds £10,000, then sub-metering should be considered to provide more accurate information. Gas, oil and electricity sub-meters can normally be installed for a few hundred pounds each.
- The audits must relate to an appropriate timeframe that should be long enough to encompass all stages of a furnace's operation. For example, audits of batch furnaces must include consideration of loading/unloading, warm-up/cool down and any idle time between batches. The same concept applies to continuous furnaces where you will need to encompass product changes, maintenance, weekend set-back etc.

### Detailed Audits

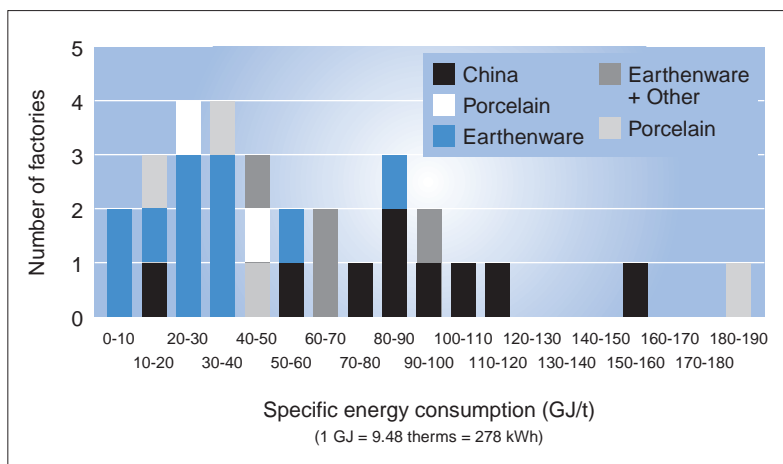
- Most furnaces will justify more detailed analysis of material use, energy use and/or production costs. The approach used for each detailed audit is as follows:
  - a) An imaginary 'envelope' is drawn around the furnace.
  - b) All input and output streams that pass through the 'envelope' are identified.
  - c) The magnitude of each stream is quantified using common units (e.g. tonnes of material, kWh of energy or financial value).
  - d) A balance sheet is constructed comparing inputs and outputs.
  - e) The balance sheet is critically reviewed to identify areas of unnecessary use or wastage, e.g. materials wastage due to off-spec product, energy wastage due to inadequate insulation, excessive maintenance expenditure etc.
- The time and effort required to complete detailed audits will depend on the size and complexity of the furnace. As a general rule, detailed audits are recommended for all furnaces where annual materials, energy, labour or maintenance costs individually exceed £10,000.
- Take your time when compiling the audits and use the opportunity to question why things are being done in the way that they are. Opportunities for cost savings will almost certainly present themselves.
- When compiling the materials balance, remember to allow for any chemical changes that occur to the product, the driving off of any volatile components, and materials lost due to off-spec production, combination with slag etc.
- The energy balance should include inputs such as feedstock, fuel, combustion and dilution air and electrical energy; and outputs such as product, kiln furniture, flue gases, exhaust gases and radiation/convection from the hot furnace shell.
- When calculating the energy content of the product remember to consider its:
  - temperature: which will probably be higher than that of the feedstock;
  - phase: molten products will have absorbed the latent heat of fusion;
  - composition: if chemical changes have occurred, the product's energy content will have either increased (endothermic change), or decreased (exothermic change).
- In the cost audit, labour costs should be subdivided to show:
  - supervisor vs operator costs;
  - overtime vs normal working;
  - time lost due to sickness;
  - time lost due to absenteeism;
  - labour cost of each process step, e.g. loading, unloading, QA.
- Maintenance costs should be subdivided to show:
  - planned vs breakdown maintenance;
  - direct employed vs contract works;
  - maintenance costs of specific equipment, e.g. burners, refractories, heat recovery plant etc.
- If the technical expertise required to undertake a detailed audit is not available from within your own organisation, consider using external specialists, for example:
  - furnace manufacturers;
  - trade associations;
  - consulting engineers.

**For further information, refer to the Core Guides (see the fax-back form).**

A simple audit of furnace performance (see Fact File M1) will provide the following:

- **furnace yield (quantity of useable production per unit of feedstock);**
- **specific energy consumption (energy used per unit of product);**
- **specific production cost (cost per unit of product).**

Quantifying furnace performance in this way allows comparison with external benchmark figures. This comparison will show whether your furnace is performing better or worse than might reasonably be expected and by how much. To be meaningful, benchmark figures need to be product-specific. Fortunately, much research has been undertaken in recent years and a wide range of benchmark data is now freely available covering most industry sectors.



Overall SEC for tableware production

### KEY POINTS

- Benchmark figures are available from a number of sources including:
  - furnace manufacturers;
  - trade associations;
  - the Energy Efficiency Best Practice Programme (EEBPP).
- Manufacturers' figures should be treated with some caution as they often relate to ideal, steady state operation that is rarely achieved in the real world. For example, their data is unlikely to allow for the impact of idle time, product changes etc. that can significantly reduce a furnace's overall energy efficiency.
- The benchmark data provided via the EEBPP is contained within the Good Practice Guides and Energy Consumption Guides listed as 'Core Guides' on the fax-back order form at the back of this Guide. All are available to UK industry free of charge.
- Most of the EEBPP benchmark data relates to specific energy consumption (SEC) and reflects the range of energy performance being achieved in practice by various industry sectors.
- The highest energy users are typically found to have SECs that are 2 – 3 times higher than the lowest (see bar chart above).
- This spread in SECs is largely caused by differences in furnace operating procedures, so improvements can often be made at little or no-cost.
- The EEBPP publications also include information on specific energy cost (cost of energy used per unit of production).
- Electric furnaces tend to have a lower specific energy consumption than equivalent gas or oil fired furnaces. However, as electricity is substantially more expensive than gas or oil (see Fact File M3), the specific energy cost may actually be higher for electrically heated furnaces.

**For further information, refer to the Core Guides (see the fax-back form).**

*Effective energy purchasing is the quickest and easiest way of reducing your energy and production costs. Price reductions of up to 20% are potentially available at no cost.*

*De-regulation of the energy supply market is now complete and so all furnace operators should be routinely seeking competitive quotations to ensure they get the best price. With electricity, there is the opportunity to reduce costs still further by careful selection of the optimum tariff structure.*

### KEY POINTS

#### Electricity

- Seek competitive prices from a number of suppliers – do not just accept your local electricity company's offer.
- To enter the competitive electricity market you need special electronic metering installed (COP), complete with modems to allow remote reading. Contact your local electricity company's meter operating section. The cost associated with installing and maintaining the metering equipment should be more than offset by the savings made by competitive purchasing.
- To get the best prices, provide potential suppliers with accurate consumption data for your site. As a minimum, provide a year's monthly figures, including day/night split, maximum demand levels and your MPAN number. If you have COP metering already, ask your existing supplier for half-hourly consumption data on disk – there may be a nominal charge.
- The true price of electricity is highly seasonal, rising sharply during November – February. Some suppliers will offer longer than 12 month contracts if the extra months included are cheap summer ones. For example, you should be able to negotiate a one-off 18-month offer if your contract is due for renewal on 1st April. The six additional months of April – October are all 'cheap' and hence the supplier is able to offer you a particularly attractive average price over the full 18 month contract period.
- Choose the right tariff structure. If you use more than 15% of your electricity at night (most factories do), choose a day/night tariff. If you can manage your electrical load, consider a type of tariff which charges peak rates during winter weekday evenings (16.00 – 19.00 Monday – Friday, November – February), in exchange for lower rates at other times. These tariffs are attractive if you can significantly reduce your factory's electrical load during the peak charging periods.

- Check your agreed supply capacity (or availability) against your actual demand – don't pay for unnecessary spare capacity.
- Check that your Power Factor is acceptable. Power Factor can be improved by the installation of correction capacitors which should be considered if:
  - your Power Factor is less than 0.9;
  - your electricity bill shows any 'Power Factor Penalty' charges;
  - your electricity bill shows any 'Reactive Power' charges.

#### Natural Gas

- Seek competitive prices from a number of suppliers.
- Provide potential suppliers with accurate consumption data for your site and your meter point reference number (shown on your bills).
- Consider two or three-year contracts, but insist on an annual competitive break clause. This will allow you to test the market each year. If you are able to obtain a better price than that offered by your current supplier, it should drop its price to match, or release you from the remaining period of the contract.
- Check for contract termination notice clauses (otherwise contracts may automatically renew at the supplier's chosen price).
- All contracts will specify:
  - maximum offtake rates;
  - a minimum 'take or pay' volume (usually 70 – 80% of nominated annual usage).

- Check the contract reflects your requirements and negotiate as necessary. This can be particularly important if your production rates, and hence gas usage, are variable or unpredictable. However, you must be prepared to pay more for your gas in exchange for increased flexibility on volume usage.
- If you are planning to install a new or upgraded gas supply, be aware that competition has now been extended to the provision of the site-works (gas main, governors, meters etc.). There are a number of authorised competitive organisations to provide these facilities.

- If your furnace has dual-fuel burners, consider a cheaper, interruptible gas supply contract, e.g. using oil or liquefied petroleum gas (LPG) as standby fuel, but do not underestimate the potential disruption caused to furnace operation on fuel changeover.

#### **Fuel Oil and LPG**

- Consider forming a purchasing consortium with other local businesses.
- Avoid deliveries of part tanker loads – they are more expensive.
- Keep your storage tanks full during summer, when fuel prices are lowest.

**For further information, refer to the Core Guides (see the fax-back form).**

*Effective furnace operation is impossible without proper raw materials or feedstock quality control. The critical parameters will vary from process to process and may include size, chemical composition, moisture content and temperature.*

*Management systems should be put in place to ensure that raw materials quality is maintained at all times. The use of recycled materials as feedstock presents particular problems and requires even more stringent management control.*

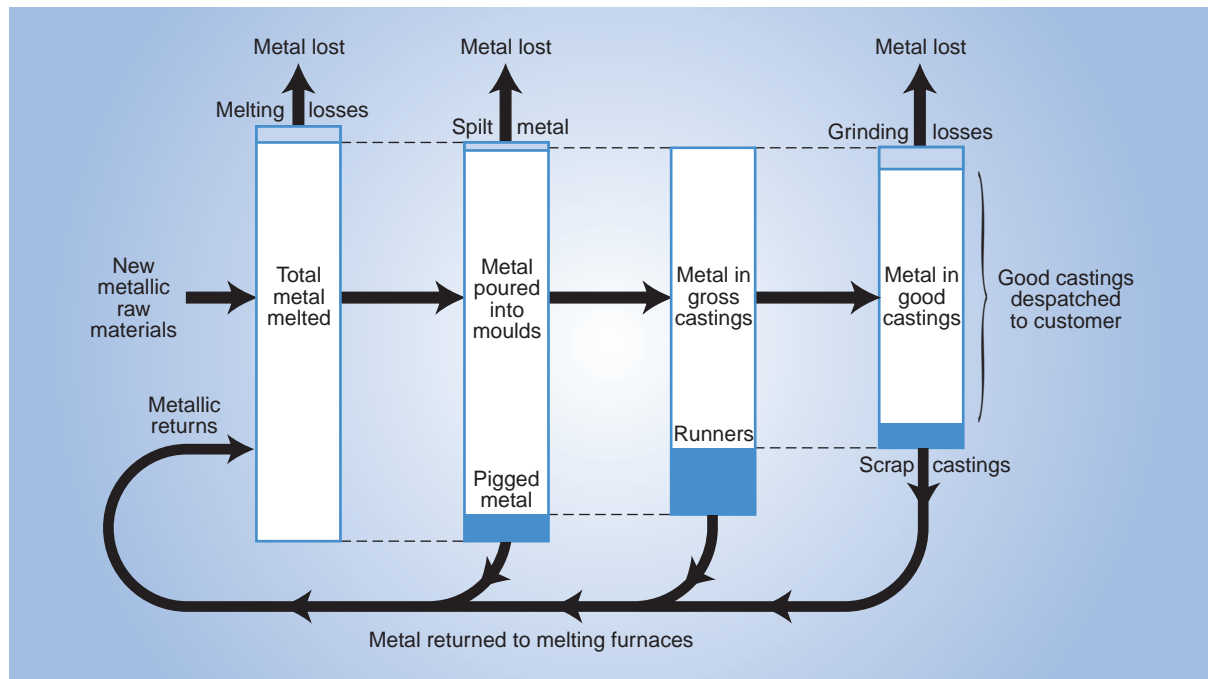
### KEY POINTS

- Raw materials and feedstock costs can be minimised by effective purchasing. Any cost savings can easily be wiped out, however, if the cheaper materials are of poorer/inconsistent quality or have uncertain availability.
- Undersized feedstock may cause bridging or other charging problems and may reduce furnace capacity if the overall charge density is reduced.
- Oversized feedstock may cause blockages or heat transfer (chill) problems. These can reduce furnace capacity and product quality.
- Contaminants are potentially dangerous and can cause fire or explosion hazards. At the very least, they may cause problems such as slagging or may limit the rate at which heat may be applied to the process. This in turn can lead to:
  - reduced production rates;
  - increased energy consumption;
  - higher maintenance costs;
  - lower product quality;
  - increased scrap rates;
  - unwanted environmental emissions.
- Extra care must be taken to maintain feedstock quality when processing re-cycled materials.
- Materials recycled from sources outside your direct control, e.g. public recycling of glass bottles, present particular problems.
- Contaminated or otherwise substandard feedstock can sometimes be accommodated by:
  - limited blending with higher quality material (which can be acceptable if percentages are held below a critical limit);
  - pre-treatment to remove contaminants etc. (although this can be expensive);
  - appropriate furnace design, e.g. two-stage heating to allow, for example, moisture to be safely removed at lower temperatures prior to full firing.
- Some feedstock defects may not become apparent until the material is processed in the furnace. Under these circumstances, it is important to recognise that feedstock quality is the cause of what may at first have appeared to have been a furnace related problem.
- Ensure that you provide your raw materials suppliers with a comprehensive specification which must include the acceptable limits (if any), for the quantities of each and every potential contaminant.
- A system of advice notes should be adopted and regular in-house laboratory checks should be made to ensure that raw materials properties remain as specified.
- Ensure raw materials of differing quality or specification are appropriately labelled and segregated in storage.
- Take care, when storing and handling raw materials, to minimise any physical or chemical degradation that could affect furnace performance.
- The same quality control principles must be applied even when the feedstock comes from another process within your factory or organisation.
- Consider alternative formats for raw materials deliveries – these may ease handling and furnace loading.
- The pre-heating of feedstock can provide energy efficiency and productivity benefits particularly if provided by:
  - hot feeding from a previous process (Fact File M6);
  - waste heat recovery (Fact File T8).

**For further information, refer to the Core Guides (see the fax-back form), plus:**

Non-ferrous metals

GPCS 344 *Energy savings from small, efficient melting and holding furnaces*



*Routes taken by metal from melting to casting dispatch*

Furnace yield can be defined as quantity of useable product per unit feedstock. There is often a trade-off between throughput and product quality that means furnace yield can be reduced at high throughputs.

Improving the way furnaces are managed can improve the balance for maximum yield. Optimising furnace operations will increase throughput and minimise waste by improving product quality, thus improving yield.

Furnaces should not be considered in isolation from any upstream or downstream processes. These processes can act as bottlenecks, thereby limiting the throughput of the furnace. The scheduling of successive operations may offer scope for improvement. Similarly, material lost in downstream processing effectively reduces the useful yield of the furnace.

### KEY POINTS

- Furnace throughput can often be limited by a single stage or factor, e.g. charging/unloading or rate of heat transfer. Aim to identify the limiting bottleneck for each furnace, remembering to consider upstream and downstream processes when appropriate.
- Feedstock must be on-spec to prevent unnecessary/wasted firing within the furnace (Fact File M4).
- Have clearly defined product specifications and stick to them. Avoid over-processing, e.g. do not heat products to higher temperatures or for longer than strictly necessary.
- For continuous furnaces, consider special operating regimes at start-up, e.g. elevated temperatures or oxygen enrichment, to obtain on-spec product as quickly as possible, thereby minimising waste.
- Minimise product degradation in the furnace, e.g. by ensuring the correct temperature profile and furnace atmosphere. Prevent mechanical damage by providing adequate means of support.
- Ensure that any by-products are quickly and effectively removed from the stock to prevent contamination. This may involve more frequent slag removal or increased extraction rates for exhaust gases.

- Accurately weigh the feedstock and product in order to determine yield and continually monitor it so that any trends can be identified.
- Identify the key variables that affect throughput and product quality and also monitor these. A number of monitoring and assessment methods are now available, e.g. statistical process control, which provide a systematic approach to this potentially complex management issue.
- Use rapid and effective Quality Assurance techniques, e.g. hot inspection, to ensure that any furnace problems are quickly identified, thereby minimising the production of off-spec material. In intermittent furnaces, faster QA analysis techniques can reduce the time that batches are held pending acceptance and hence can reduce overall cycle times.
- Ensure valuable product is not wasted during subsequent processing (or transfer to it). Utilisation efficiency of materials produced by furnaces can be improved by attention to:
  - design, e.g. to reduce the quantity of molten metal used in runners during subsequent casting operations;
  - operation, e.g. to ensure product is not damaged in subsequent transfer and storage;
  - rectification, e.g. repair of minor blemishes in sanitaryware to avoid scrapping the piece.
- Operate effective maintenance regimes to ensure continuing high yields.

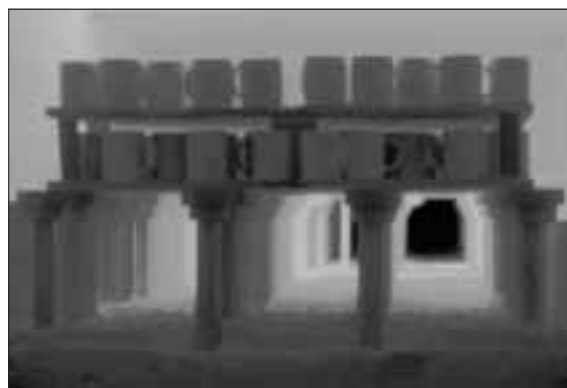
### For further information, refer to the Core Guides (see the fax-back form), plus:

Ferrous metals	GPG 17	<i>Achieving high yields in ferrous foundries</i>
	GPCS 37	<i>Computer simulation of solidification in ferrous foundries</i>
	GPCS 161	<i>Cupola melting of cast iron</i>
	GPCS 353	<i>The use of filters in ferrous foundries</i>
Non-ferrous metals	GPG 142	<i>Improving metal utilisation in aluminium foundries</i>
	GPCS 36	<i>Computer simulation of solidification in non-ferrous sand foundries</i>
	GPCS 282	<i>Use of molten metal filters in non-ferrous foundries</i>

*The way a furnace is charged can have a significant effect on its safe operation, yield and energy consumption.*

*There are two principal issues:*

- **the speed with which the furnace is charged and unloaded;**
- **the physical configuration of the charge and the way in which it is supported.**



*When the furnace forms part of a larger manufacturing process, consideration also needs to be given to the way in which the charging and unloading procedures interface with the neighbouring operations.*

### KEY POINTS

- Access doors can represent a route for significant heat loss when used to charge or unload materials from a hot furnace. Any such doors must be well fitting and adequately insulated. Heat losses during charging/unloading can be minimised by making sure that doors are no larger than necessary and that they remain open for the minimum possible time.
- Charging and unloading times can be minimised by careful attention to operating procedures. Mechanical or automatic systems should be considered, although, quite apart from the cost implications, their use may be limited by space constraints or the need to handle a wide variety of materials.
- No effort should be spared to identify the optimum charging procedures and management systems should then be put in place to ensure that these procedures are adhered to.
- Both intermittent and continuous furnaces benefit from consistent charging procedures as these help to maintain uniform firing conditions and hence product quality.
- Accurately weigh stock into and out of the furnace to allow true yield to be monitored.
- If furniture is required to support the stock, make sure that its design allows effective heat transfer (particularly to the base of the stock), and prevents degradation by mechanical damage.
- Use low thermal mass furniture to reduce energy requirements for warm-up (modern high temperature alloys can often be used in place of conventional refractories).
- Water cooled support structures are sometimes necessary, but lead to large energy losses. Their design should be critically reviewed as energy efficient modifications can sometimes be made.
- Be aware that poor plant layout can lead to delays in charging or unloading a furnace. It can also lead to loss of useful stock heat between processes.
- Hot charging of furnaces, i.e. using hot material from an upstream process, can reduce furnace energy requirements considerably. Heat can be retained in stock between processes by using insulated transfer routes. In some cases, supplementary heating can be desirable during transfer to prevent surface cooling of the stock.

### For further information, refer to the Core Guides (see the fax-back form), plus:

Ferrous metals	GPCS 263	<i>Hot charging practice for continuous steel reheating furnaces</i>
	FPP 47	<i>Quantifying important factors in iron melting in medium frequency coreless induction furnaces</i>
Non-ferrous metals	GPCS 344	<i>Energy savings from small, efficient melting and holding furnaces</i>
Ceramics	GPG 244	<i>The use of low thermal mass materials and systems in the ceramic industries</i>

*Making the right decisions about which furnace to use, and when, can bring a number of benefits including:*

- **maximising product throughput;**
- **minimising energy use;**
- **minimising furnace use;**
- **achieving delivery dates;**
- **minimising work in progress inventory;**
- **minimising time from customer order to delivery.**

*Determining the optimum schedule can be a complex exercise and needs to be undertaken in a systematic manner. Computer based systems are available to perform the task automatically.*



*The control cabin at Roundwood rolling mill*

### KEY POINTS

- Different designs of furnace have different performance characteristics. Therefore, the most efficient furnace for one task may not be the most efficient on another, e.g. continuous furnaces are most suitable for large volume products, and intermittent furnaces are most suitable for small volume, speciality products.
- Furnaces are most efficient when fully laden. Avoid part-load operation by, e.g. stock-piling and running fewer furnace shifts.
- Try to avoid mixed stock loads as furnace conditions will need to be set for the most demanding product, potentially causing 'over processing' of the remainder. Consider segregating different stock types and processing them separately.
- When making scheduling decisions take full account of all operating costs involved. This is particularly important when making 'special' products that require a change to normal furnace conditions. The true cost of warm up, cool-down and part-load operation can be very high.
- Schedule planned maintenance carefully, particularly if a cool-down is required.
- Scheduling decisions can be based on manual analysis or, for more complex situations, computer based 'expert systems' (Fact File T6) can be invaluable.

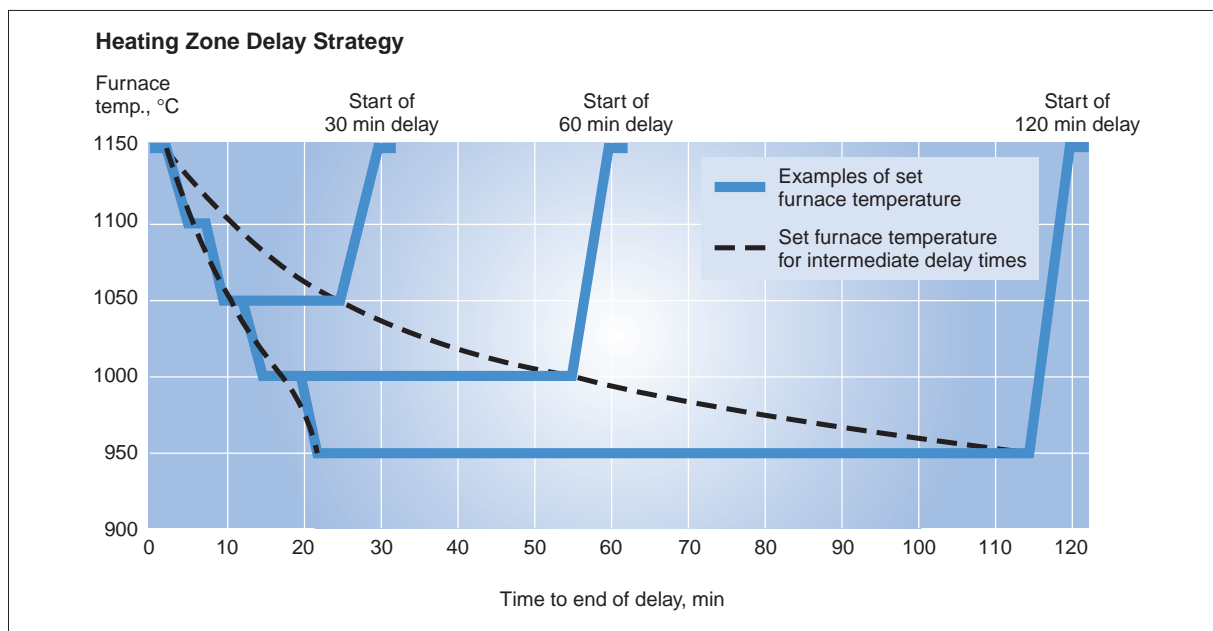
**For further information, refer to the Core Guides (see the fax-back form), plus:**

All sectors

GPCS 135 *Furnace scheduling advisory system*

All furnaces will be, from time to time, subject to operational delays. It is important to have clear strategies for dealing with these.

Failure to put adequate procedures in place will lead to lost production, energy wastage and possibly damage to the furnace.



Delay strategy for a walking beam type furnace reheating 140 mm square billets

### KEY POINTS

- Delays or interruptions to furnace operation will fall into one of two categories:
  - scheduled, e.g. shift changes or meal breaks;
  - unscheduled, e.g. breakdowns or feed stock shortages.
- A strategy for dealing with delays must be developed in advance, documented and communicated to plant operators.
- The strategy should include consideration of:
  - changing stock throughput rates;
  - reducing furnace temperature;
  - sealing furnace doors;
  - shutdown of the furnace in response to prolonged delays.
- The actions required will vary depending upon the anticipated duration of the delay. For example, a short delay may require little or no change to furnace operations, whereas a longer delay may require major action to prevent loss of product or damage to the furnace.
- Information systems are required so that the cause and likely duration of any delay can be quickly ascertained and communicated to those responsible for operating the furnace.
- The delay strategy should also include advice on when to re-start a furnace if shutdown:
  - too late a start-up will cause lost production;
  - too early a start-up will lead to energy wastage.
- Computerised 'expert systems' can help in the management of operational delays (Fact File T6).
- The causes of operational delays should be rigorously logged and periodically analysed to identify any underlying weaknesses. Steps should be taken to prevent repeat occurrences.

**For further information, refer to the Core Guides (see the fax-back form).**

*Furnace operations can be complex, and staff should be trained and supervised accordingly. As a minimum, standard operating procedures must be compiled for all aspects of furnace operation and staff trained to follow them. Ongoing supervision will be required to ensure that the procedures are rigorously adhered to.*

*Motivated and empowered staff will continually seek ways to improve all aspects of furnace operation.*

*Achieving this may take some time and will require support and commitment from managers at all levels. The benefits that will arise from having a motivated and fulfilled workforce will, however, repay the effort involved.*



*A team approach to energy management*

### KEY POINTS

- As a first stage, develop and document standard operating procedures covering all stages of furnace operation including:
  - start-up;
  - loading and unloading;
  - firing;
  - shutdown;
  - delays in production;
  - emergencies.
- Ensure operators are fully trained to follow the standard operating procedures.
- Put in place adequate supervision to check that these procedures are always followed.
- Start-up procedures should be flexible enough to take account of any residual heat within the furnace or stock. Warm-up times should be varied accordingly.
- Computerised control systems are generally more effective at maintaining optimum furnace conditions than even the most experienced staff.
- Computers can be used to fully automate control, or can provide detailed guidance to operators on the required operating parameters (this information will be automatically updated in line with any changes in furnace conditions etc.).
- Consider external training for operators, e.g. Continuing Professional Development courses.
- Encourage staff participation in solving problems and identifying opportunities for improvements. Consider:
  - forming efficiency teams;
  - suggestion schemes;
  - publicising improvements both within and outside the company.

**For further information, refer to the Core Guides (see the fax-back form), plus:**

All sectors

NPCS 89 *Energy efficiency training through continuing professional development*

Ceramics

GPCS 345 *Energy management techniques in the pottery industry*

*Labour costs, like all others associated with furnace operation, can and should be managed effectively.*



### KEY POINTS

- The following issues should be considered:
  - operating procedures;
  - numbers of staff employed;
  - division of labour;
  - versatility of staff;
  - number of furnaces served;
  - shift patterns;
  - pay rates;
  - levels of supervision;
  - labour required for breakdown repairs;
  - maintenance.
- The greatest labour requirements can often be associated with the loading and unloading of the furnace.
- Labour requirements for loading can be minimised by the careful selection of types, forms and methods of raw materials delivery.
- Aim to minimise stock handling requirements by the careful consideration of plant layout and scheduling of operations.
- Make best use of mechanical handling aids.
- Staff versatility can be improved by providing additional training (Fact File M9).
- Effective planned preventative maintenance procedures can reduce engineering labour costs and offer scope for the use of contract staff.
- Automatic controls and computerised 'expert systems' (Fact File T6) can allow labour requirements to be reduced, by streamlining operations, product changes etc. to minimise labour involvement.

**For further information, refer to the Core Guides (see the fax-back form), plus:**

Glass

GPCS 251 *An energy management and investment campaign at a glass plant*

*Without effective maintenance, all other efforts to improve furnace performance will soon be wasted.*

*Proper maintenance has to be an integral part of any industrial process. This is particularly true of furnaces because of the aggressive nature of many of the materials handled, combined with the use of very high temperatures.*

*The consequences of inadequate maintenance can be severe and can include reduced throughput, increased energy consumption and damage to the furnace itself. Deterioration in performance can be detected by regular audits and effective monitoring.*



*New ducting to recover exhaust from kiln pre-heater*

### KEY POINTS

- Effective planned preventative maintenance will lead to improved furnace availability and reduced operating and labour costs. The cost implications of unscheduled stoppages due to breakdowns should not be underestimated, particularly if it takes some time to re-establish stable furnace conditions.
- If a breakdown does occur, it is important to investigate the cause fully in order that steps can be taken to prevent a reoccurrence.
- Maintenance and calibration of control systems are important. Reliable and accurate control of furnace conditions is an essential requirement of efficient operation.
- Ensure drive belts on fans, etc. are regularly changed and correctly tensioned to prevent premature failure
- When installing new or replacement 3-phase motors check that the direction of rotation is correct (fans will quite happily run backwards – but at reduced performance).
- Change filter elements regularly to prevent:
  - reduced air flows;
  - changes to combustion and kiln conditions;
  - dirt carry over;
  - increased pollution.
- Check and replace seals to prevent unwanted movement of hot and cold air into and out of the furnace. Don't forget internal seals if the furnace is compartmentalised.
- Inspect flues and ducts for blockages.
- Clean heat transfer surfaces, e.g. on waste heat recovery systems, regularly.
- Check the condition of burners and quarls.
- Monitor refractory/insulation performance by visual inspection and by surface temperature measurement, e.g. using infrared photometry. The economics of the refractory works should be assessed in the context of the cost of increased energy use as the insulation performance deteriorates, and refractory repairs/replacement scheduled accordingly.
- Clean plant regularly to prevent refractory erosion.
- The quality of the raw materials processed can have a significant effect on the rate of erosion/corrosion that occurs inside the furnace. Be particularly aware of the destructive effect that trace contaminants can have.

**For further information, refer to the Core Guides (see the fax-back form).**

*It is often said that 'if you don't measure it, you can't manage it' and this is particularly true of the parameters that affect efficient furnace operation. Without adequate information it is difficult to make accurate decisions.*

*Comprehensive monitoring procedures are essential and should encompass specific items such as temperatures and pressures as well as broader ones like throughput, energy use and maintenance costs.*

*Most importantly, procedures must be put in place to analyse the data recorded and to instigate appropriate actions in response to the results. Without these additional steps, monitoring alone will produce little benefit. Once reliable monitoring has been established, targets should be set with the aim of maintaining, or preferably improving, furnace performance.*



*A furnace control panel*

### KEY POINTS

- The frequency of monitoring should be selected depending upon the parameter concerned. Generally, it is better to sample more frequently than required, than to have insufficient data.
- Regularly measure and record key parameters:
  - furnace internal temperature;
  - furnace pressure;
  - cooling water temperatures;
  - furnace shell temperature;
  - furnace atmosphere;
  - burner combustion efficiency;
  - throughput;
  - yield;
  - energy usage;
  - specific energy consumption;
  - maintenance requirements;
  - labour requirements;
  - resistance and reactance (induction furnaces).
- Data must relate to a specific furnace and/or specific product. This may require keeping more detailed production records.

- Where practicable, install additional sub-metering to allow the energy consumption of individual furnaces to be monitored and invest in portable test equipment, e.g. combustion analysers and optical pyrometers, as necessary.
- Plot data to allow trends to be identified and to highlight any anomalous behaviour. Determine 'norms' for all parameters
- Data analysis techniques should be appropriate to the complexity of the operation. Manual manipulation may be adequate for small, intermittent furnaces, but for most applications the use of a computer will be beneficial. This can range from the use of a spreadsheet package on a PC to analyse data that have been collected by hand, through to a fully automatic data logging and analysis system.
- Reports should be generated that are concise and easy to read. The reports should highlight anomalous results and guide the recipient towards appropriate action. The use of 'exception reporting', i.e. only issuing reports when there is something wrong, can be an effective way of reducing paperwork and of ensuring that when a report is issued it receives the attention that it demands.
- Put in place standard operating procedures to ensure appropriate action is taken in response to the monitoring results.
- Plot specific energy consumption against production. Investigate causes of unusually high or low figures. Learn from these investigations and set targets for improvements.
- Targets for future performance can be best set following a detailed audit of furnace performance (Fact File M1). The audit will identify where and how improvements can be made.
- Ensure targets are supported by appropriate implementation timescales.
- Implement any changes one at a time, to allow their effectiveness to be monitored.
- Provide regular feedback on achievements to staff at all levels. This will reinforce the value of rigorous monitoring to them, and improve staff motivation through a greater sense of involvement.

### For further information, refer to the Core Guides (see the fax-back form), plus:

All sectors	GPCS 183 <i>Performance monitoring of a re-heat furnace</i>
	GPCS 321 <i>Energy monitoring on large steel reheating furnaces</i>
Ferrous metals	GPCS 213 <i>Demonstrating good practice in medium frequency coreless induction furnaces</i>
Glass	GPCS 251 <i>An energy management and investment campaign at a glass plant</i>
Ceramics	GPCS 345 <i>Energy management techniques in the pottery industry</i>

*Environmental issues and legislation are already having a significant impact on furnace operators and this is likely to increase. More information about environmental regulations can be obtained through the Environment and Energy Helpline on 0800 585794.*

*Environmental issues are best addressed when integrated within a systematic management approach which considers all aspects of furnace operation. This will ensure an effective and efficient process. By taking a broader view of environmental issues and not just using 'end of pipe' solutions, you will often increase the efficiency and lower the cost of your operations.*

### KEY POINTS

#### Emissions

- There are two main sources of potentially harmful emissions from furnaces:
  - products of combustion;
  - products of physical/chemical changes to the stock.
- Products of combustion include:
  - SO<sub>2</sub> (when burning oil or coal);
  - NO<sub>x</sub> (increases with flame temperature);
  - CO;
  - CO<sub>2</sub>.
- Products of physical/chemical stock changes include:
  - acid gases (HCl etc.);
  - volatile organic compounds (VOCs);
  - heavy metals;
  - particulates.
- Consider also the environmental impact of breaking up and disposing of redundant furnaces. Older furnaces may contain materials that present an environmental hazard on disposal, e.g. asbestos and heavy metals. As such, a licensed contractor may be required to dispose of certain materials in an appropriate manner.
- Pollution may result from releases into air, water or onto land.
- A two-stage approach should be taken to reduce emissions:
  - firstly, reduce the amount generated, e.g. by close attention to combustion control;
  - secondly, install abatement equipment, e.g. scrubbers or grit arrestors.
- When installing abatement equipment, be aware of possible adverse effects on furnace operating conditions, such as increased exhaust backpressure.
- The most harmful or potentially polluting processes and substances are formally 'prescribed'. They are regulated by environmental legislation (see below).

#### Legislation

- Under the Environmental Protection Act 1990, it is an offence to:
  - operate a prescribed process without the appropriate authorisation;
  - operate a prescribed process in contravention of the authorisation conditions.
- There are two regulatory bodies that can authorise the operation of a prescribed process:
  - the local authority, via its environmental health department;
  - the Environment Agency, via its network of regional offices.
- In principle, local authorities will deal with the 'less polluting' processes and those that involve emissions only to air. These processes require only Local Air Pollution Control (LAPC) authorisation.
- Larger, 'more polluting' processes and those involving emissions other than solely to air, require Integrated Pollution Control (IPC) authorisation from the Environment Agency.
- Contact the environmental health department of your local authority or your nearest Environment Agency office for

advice on whether or not an authorisation is required.

- LAPC and IPC authorisations will specify an emissions limit for each prescribed substance relevant to your process and will require that a monitoring programme is established to ensure that emissions remain within the limits of the authorisation.

- Authorisations will recommend that appropriate techniques be adopted to prevent or minimise releases and render harmless any prescribed substances. Guidance is available via:

- Process Guidance Notes for LAPC authorised processes;
- Chief Inspectors Guidance Notes for IPC authorised processes.

- Your relevant authorising body will be able to advise you on the appropriate publications.

## Management Plan

- Establish a management plan to ensure that relevant issues are made the responsibility of a designated person.

- When establishing a management plan, consideration should be given to:

- a) Relevant legislation, regulations and codes of practice – what emissions need to be controlled?
- b) Existing management practices – are emissions controlled in the most effective way?
- c) Previous incidents – have there been any specific problems in the past that can be learned from?

- Certain furnaces may require continuous monitoring. Even if an authorisation is not required, monitoring emissions will allow effective management of furnace performance.

- Consider general operations, materials handling, commissioning and the technical requirements for chimneys, vents and process exhausts. These issues should be included in an effective management system.

## Future Controls

- The increasing concern about global warming and associated carbon dioxide emissions has led the Government to set a target of reducing such emissions by 20% between 1990 and 2010 as part of its climate change strategy. This target may be achieved by reducing industrial energy use.

- Changes in legislation will occur over the next few years to the LAPC and IPC regime with the implementation of Integrated Pollution Prevention and Control (IPPC). How this will be applied in practice has yet to be resolved, but installations will have to ensure that energy is used efficiently. In addition, it will require the effective management of inputs to industrial processes. Establishing an effective management system now will enable effective control of inputs and emissions, thereby pre-empting future legislation and embracing best practice.

## Further Advice

- In addition to your local authority and Environment Agency office, expert advice can be obtained free of charge from the Environment and Energy Helpline on **0800 585794**.

**For further information, refer to the Core Guides (see the fax-back form).**

*Appropriate financial assessment is essential when considering expenditure on new furnaces or retrofitting modifications. Many modifications may be technically viable, e.g. the incorporation of waste heat recovery equipment, but may be uneconomic if the operating parameters for the furnace are inappropriate.*

*Similarly, choosing between alternative furnace designs or suppliers simply on the basis of initial price can be a costly mistake in the longer term. It is also important to consider the impact of ongoing annual operating costs by using more sophisticated financial assessment techniques.*



### KEY POINTS

■ When assessing the economic viability of any project, full account must be taken of all costs involved and the savings or income that should result.

■ Costs may include:

- design;
- purchase of equipment;
- mechanical and electrical installation;
- builders work;
- lost production during changeover.

■ Benefits may include:

- increased production (higher rates, and/or yields);
- higher quality (allowing premium price);
- energy savings;
- improved reliability;
- reduced maintenance;
- greater flexibility;
- lower labour requirements;
- ability to use cheaper raw materials;
- cheaper disposal costs when the furnace is finally scrapped.

■ Finding out precisely how the business case should be prepared will give the best chance of it being accepted.

■ Minor projects (such as upgrading insulation) can be assessed using 'simple payback period', i.e.

$$\frac{\text{Total cost}}{\text{Total annual benefits}}$$

■ The quicker the payback period (in years), the more attractive the project. Most companies define maximum acceptable payback times (typically 2 – 5 years) beyond which projects are considered to be uneconomic.

■ For larger, complex projects more sophisticated financial assessment techniques such as discounted cash flow (DCF) should be used.

■ DCF takes account of costs/savings throughout the expected life of the project and is particularly useful when considering:

- alternative types of new furnace;
- the timing of furnace replacement, e.g. it may be better to replace an inefficient furnace now, rather than wait a few more years until it is worn out.

■ Step by step guidance on performing DCF analyses is given in Good Practice Guide 69 (see below).

■ Some items of energy efficiency equipment are eligible for a financial incentive. Call the Environment and Energy Helpline (0800 585794) for more details of 'enhanced capital allowances'.

**For further information, refer to the Core Guides (see the fax-back form), plus:**

All sectors

GPG 69

Investment appraisal for industrial energy efficiency

The correct choice of fuel is one of the most fundamental issues influencing product quality and furnace operating costs. A number of issues need to be considered when selecting a fuel type including:

- **price;**
- **combustion/heat transfer characteristics;**
- **cleanliness of combustion and emissions;**
- **special fuel storage or handling requirements;**
- **reliability of supply.**

While it is sometimes possible to convert existing furnaces to use different fuels, this is rarely straightforward. It is particularly important, therefore, to select the correct fuel when specifying a new furnace.

### KEY POINTS

- Using electricity to heat furnaces will often provide the lowest local energy *consumption* but the highest energy *cost*.

Approximate cost of fuels relative to natural gas	
Natural gas	1
Fuel oil	1
LPG	2.5
Electricity	5

- Fuel prices can be minimised by competitive tendering (Fact File M3).
- Electric heating tends to be more appropriate for smaller furnaces.
- Fuel choice may be dictated by product requirements, e.g. high purity or the need to maintain a controlled atmosphere within the furnace.
- Local emissions standards must also be considered when selecting a furnace fuel (Fact File M13)
- Natural gas is often the favoured fuel for furnace operation because:
  - it is relatively clean burning, without soot or sulphur dioxide (SO<sub>2</sub>) emissions and produces less carbon dioxide (CO<sub>2</sub>) than LPG, oil or coal (although nitrous oxide – NO<sub>x</sub> – emissions are higher);
  - this cleanliness makes it easier to comply with emissions standards and allows the direct firing of many products (Fact File T3);

- as a piped service it avoids the administrative burden of fuel stock control, ordering and supervision of fuel deliveries etc.;
- no on-site fuel storage is required, thereby reducing maintenance costs and avoiding the safety and environmental risks associated with bulk storage facilities.

- LPG and oil, while not offering the advantages listed above of natural gas, can yield higher thermal efficiencies and increased furnace throughput.
- LPG requires the provision of pressurised bulk storage facilities, vaporisation equipment and a gas/air mixing station to ensure correct air/fuel ratio at all firing rates.
- In addition to storage tanks, fuel oil requires effective atomisation and vaporisation to ensure correct combustion. This places special demands on oil burners, which in turn, require more regular maintenance than gas-fired burners.
- Oil flames are hotter, more luminous and larger than gas flames, and require larger firing chambers.
- Changing fuels on an existing furnace is a complex matter. The following must be considered:
  - safety implications;
  - flame shape;
  - flame intensity;
  - flame luminosity;
  - products of combustion;
  - required furnace atmosphere.

- In some circumstances it is possible to fit dual-fuel burners, i.e. burners that are capable of burning either one of two different fuels. These allow fuel changes to be made relatively quickly and may offer opportunities to burn cheaper fuels, e.g. interruptible natural gas while maintaining security of heat supply.
- Oxygen enrichment is expensive and may increase NO<sub>x</sub> emissions but allows:
  - higher flame temperatures;
  - better heat transfer;
  - the use of lower calorific value fuels;
  - more flexible control of furnace temperature.
- Oxygen enrichment can be applied as a retrofit to existing furnaces but, as with any fuel change, requires much care and special consideration.
- Furnaces using a combination of fuels, e.g. natural gas and electricity, can provide significant production and energy consumption benefits in some applications.

**For further information, refer to the Core Guides (see the fax-back form), plus:**

Ferrous metals	NPP 54	<i>Dual fuel regenerative burners</i>
Non-ferrous metals	GPCS 112	<i>Gas fired shaft furnaces</i>

*Efficient combustion will ensure that the maximum amount of heat is released from the fuel being burnt and help transfer this effectively to the stock. This, in turn, will lead to reduced emissions, improved product quality and help safeguard the structural integrity of the furnace.*

*Achieving optimum combustion requires the correct selection of burner type and the matching of it to the requirements of the furnace. Maintaining performance requires close attention to the control of key combustion parameters coupled with regular and effective maintenance of the fuel supply systems, burners and their controls.*



*Testing the air-fuel mixture on a glass furnace.*

### KEY POINTS

- Efficient and complete combustion requires the correct air/fuel ratio and adequate mixing.
- While optimum conditions will be set-up at commissioning, many factors can cause unwelcome deviations, including:
  - burner wear;
  - hysteresis (or slack) in control systems;
  - variations in fuel properties, e.g. calorific value;
  - variations in combustion air properties, e.g. temperature, particularly where pre-heat is used as a means of waste heat recovery;
  - variations in furnace pressure.
- Maintaining optimum combustion conditions requires:
  - modern automatic controls, e.g. air/fuel ratio, furnace pressure, (depending on size and type of burner);
  - routine efficiency monitoring, e.g. flue gas temperature, carbon dioxide concentration;
  - regular burner and controls maintenance.
- Where burners are required to have turn-down capability, i.e. to reduce their thermal output, the control system has particular requirements to maintain efficient combustion across the range of firing rates.
- Incorrect combustion will lead to fuel wastage, reduced throughput, poor product quality, excessive emissions and/or structural damage to the furnace.
- It is generally harder to maintain optimum combustion conditions when burning oil, compared with natural gas, because:
  - oil requires effective atomisation and vaporisation for correct combustion;
  - oil burners are often machined to close tolerances to achieve this;
  - oil can be corrosive and abrasive, leading to more rapid burner wear;
  - carbon and soot build-up will occur, affecting burner and furnace performance.
- Effective combustion control is particularly important when seeking to maintain a particular furnace atmosphere or when using oxygen enrichment.

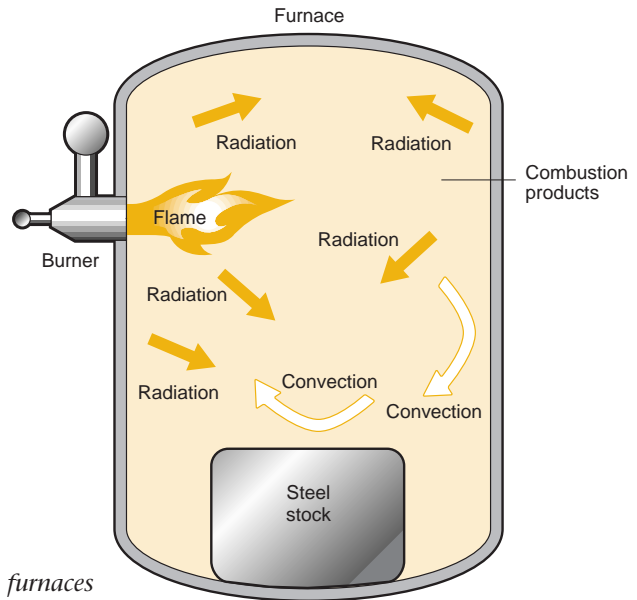
**For further information, refer to the Core Guides (see the fax-back form) plus:**

Non-ferrous metals      GPCS 344 *Energy savings from small, efficient melting and holding furnaces*

*Unless heat is transferred effectively from the burner flame, or heating element, to the stock, the throughput of the furnace will be limited and/or significant energy wastage will occur.*

*Heat transfer must also be uniform to ensure good product quality and to prevent under or overheating part of the stock.*

*Effective heat transfer requires close attention to furnace design (in particular the matching of burner equipment), combined with accurate control of furnace conditions and stock loading procedures.*



Heat transfer in furnaces

### KEY POINTS

- In most furnaces heat is transferred by two complementary mechanisms, convection and radiation.
  - In convection, heat is transferred from the flame or heating element to the stock by the movement of hot air (or the products of combustion). This movement may occur naturally due to the buoyancy of the hot gases, or may be mechanically induced using fans.
  - The final stage of the convective heat transfer process, namely the transfer of heat from the hot gases to the stock, can be accelerated by ensuring that the gas flow is turbulent. Turbulence can also help to ensure that heat transfer is uniform to all surfaces of the stock and throughout the furnace. Too much turbulence can be harmful, however, as it may lead to product degradation or cross contamination. It can also result in excessive electrical usage by the circulation fans.
  - It is important to understand the balance of heat transfer mechanisms within each furnace. This will influence other aspects of operation such as charge loading and the need for turbulence. Radiation normally dominates (particularly above 600°C).
  - With radiation, there is no need for hot gases to act as a mechanism for heat transfer.
- Instead, energy is transmitted from the flame or heating element in the form of electromagnetic radiation and this is absorbed directly by the surface of the stock. As this radiation travels in direct straight lines, stock surfaces which are not 'visible' to the flame will not be heated. In practice, this effect can be overcome by heating the refractory lining of the furnace to a high temperature such that it starts to radiate.
- For lowest energy usage, aim to maximise the rate of heat transfer, thereby minimising firing times (subject to stock constraints). Factors to consider include:
    - flame shape, luminosity and temperature (consider oxygen enrichment);
    - turbulence;
    - furnace shape;
    - furniture/stock spacing.
  - Direct firing, i.e. where the products of combustion are in direct contact with the stock, will be more efficient than indirect firing. Products of combustion may have an adverse effect on stock quality, however, and for this reason, cleaner fuels such as natural gas are often favoured.
  - When direct firing, avoid the flame coming into direct contact with the stock. Carefully control flame shape/direction or use muffles.

**For further information, refer to the Core Guides (see the fax-back form) plus:**

Ceramics

NPP32

Fast firing of decorated ceramic ware

*The atmosphere within a furnace serves a variety of purposes including:*

- **providing a mechanism for convective heat transfer to the stock;**
- **removal of the products of combustion;**
- **removal of the products of chemical or physical change within the stock;**
- **prevention of unwanted changes or degradation to the stock, e.g. the use of a reducing atmosphere to prevent product oxidation;**
- **control of unwanted air ingress or excessive loss of hot furnace gases.**

*Accordingly, the internal furnace atmosphere must be closely controlled, particularly with regard to:*

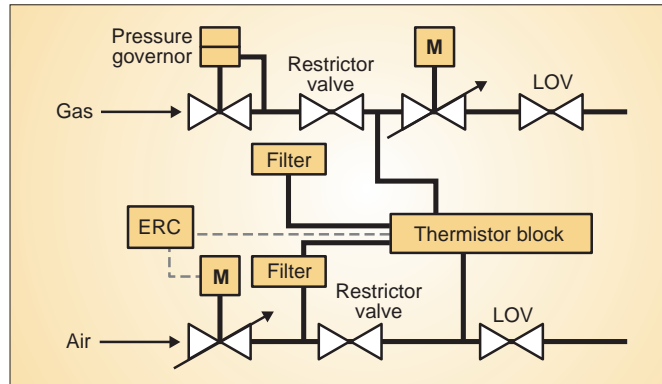
- **temperature;**
- **pressure;**
- **velocity profiles;**
- **chemical composition.**

### KEY POINTS

- The composition of the atmosphere of a furnace may need to be controlled to give the required product quality and minimum degradation.
- Common composition criteria are oxidising/reduction potential and humidity. These can be influenced by:
  - products of combustion;
  - products of chemical changes in the stock;
  - additives.
- In multi-zone furnaces, it may be important to ensure that contaminants are not carried forward from one zone to another (use correct air flow patterns and/or effective seals).
- Furnace pressure must be correctly adjusted to provide proper convective heat distribution and prevent uncontrolled ingress of ambient air, which will increase energy use and/or lead to chilling of the stock. Furnaces should usually be operated at a pressure slightly above atmospheric.
- Avoid excessive internal pressures as these will lead to leakage of hot gases out of the furnace (which may have health and safety implications or damage the external structure of the furnace).
- The correct amount of turbulence must be achieved. In general, turbulence promotes even heat transfer, but too much can be bad for some stock causing degradation or cross-contamination.
- Without adequate turbulence, the increased buoyancy of hot gases can lead to temperature stratification.
- Ensure that the sizes and positions of exhaust ports are correct in order to induce the correct hot gas flow patterns through the furnace.
- Excessive exhaust rates will cause unwanted heat loss. Inadequate exhaust rates will mean that the products of combustion/chemical change are not removed effectively.

**For further information, refer to the Core Guides (see the fax-back form).**

Close control of furnace conditions is essential for good product quality, energy efficiency and minimum emissions. The key parameters that need to be controlled will vary from furnace to furnace. Start by identifying these critical parameters and then ensure that suitable control systems are put in place to regulate each of them. Control systems need to be accurate, responsive and reliable.



Electronic ratio control

### KEY POINTS

- Key parameters to control include:
  - furnace pressure;
  - furnace temperature;
  - warm-up/cool-down rates;
  - holding time;
  - furnace atmosphere;
  - combustion efficiency;
  - air/fuel ratio;
  - fuel or electrical power input.
- Close control requires accurate measurement, e.g. using thermocouples, pressure transducers or orifice plates.
- Measurement devices must be carefully positioned to avoid false readings, e.g. thermocouples can give false readings if subject to flame impingement. In addition, pressure transducers and flow meters will not work accurately in turbulent conditions.
- Whenever possible, try to measure the required parameter directly, e.g. measure mass air flows directly rather than relying on manifold pressure as the control point.
- Many sensors are required to work in aggressive conditions when applied to furnace applications, e.g. high temperatures, chemical attack, fouling or vibration. Reliability can be improved by careful selection of the sensor type and by 'conditioning' the process stream prior to measurement, e.g. by filtration or cooling.
- Rigorous maintenance regimes (Fact File M11) are required to ensure correct control calibration and performance. All elements of the control system must be maintained namely:
  - sensor;
  - controller;
  - control device (valve, actuator etc.).
- Use the correct control algorithm, e.g. proportional, integral, derivative, for the application concerned.
- Review existing control systems to ensure that they are:
  - accurate and able to provide close control;
  - stable and able to restore conditions quickly and effectively when subject to sudden changes;
  - flexible and able to control across a wide range of set points if needed;
  - easy to use and understand;
  - reliable and easy to maintain.
- Ensure that the set points required for each control parameter are defined via standard operating procedures and that staff are trained accordingly (Fact File M9).
- When regulating gas or air flows, remember that the use of dampers is less energy efficient than alternatives such as variable speed drives (Fact File T13).
- The effective control of furnaces, while complex, is not a 'black art'. The optimum furnace conditions for any processing requirement can always be defined and formalised.
- The use of computerised control systems can lead to significant performance improvements particularly when dealing with complex multi-variables (Fact File T6).

**For further information, refer to the Core Guides (see the fax-back form) plus:**

Ferrous metals

GPCS 213 *Demonstrating good practice in medium frequency coreless induction furnaces*

*It is no longer necessary, or desirable, to operate furnaces on the basis of 'trial and error'. While the parameters affecting furnace operation are many and complex, modern mathematical modelling techniques allow them to be correlated and understood.*

*Microprocessor-based control systems can be constructed which incorporate these complex algorithms. These systems allow the impact of multiple changes in furnace conditions to be predicted and can select the correct settings for optimum performance.*

*These 'expert systems' can either be configured to provide advice on which operators can then act, or can be arranged to provide fully automatic control of the furnace itself.*



*Expert system control station*

### KEY POINTS

- Traditionally, the required furnace conditions have been arrived at by experimentation, e.g. by firing a number of test pieces.
- The above approach makes it difficult to achieve optimum settings and judge what adjustments should be made if any parameters are changed, e.g. fuel type, stock size.
- Powerful mathematical techniques now exist, e.g. Computational Fluid Dynamics (CFD), which allow the inter-relationships between all furnace variables to be modelled and hence understood.
- Even complex parameters such as heat flux profiles and convective air flow can now be effectively modelled.
- Many mathematical models use purpose-developed criteria (such as 'heat-work') as a means of predicting furnace performance.
- Computer-based 'expert systems' use these mathematical models to determine the best furnace settings for any job.
- If conditions change, or non-ideal settings are used, the 'expert system' can issue new instructions and/or activate alarms or interlocks to prevent off-spec production.

**For further information, refer to the Core Guides (see the fax-back form) plus:**

All sectors

NPP 85

*An on-line, real time, expert system optimiser to reduce energy costs*

GPCS 160

*Expert system improves performance of PLC control plant*

*The correct choice of refractory is essential to protect the furnace and minimise energy use.*

*In recent years there have been significant advances in refractory technology, particularly in the field of low thermal mass linings (which are of especial benefit in intermittent furnaces).*

*When selecting a refractory specification it is important to consider its resistance to erosion as well as its effectiveness as an insulator. Replacing or repairing worn out refractories is expensive, particularly when the cost of lost production is considered, and so longevity is a key requirement for a successful refractory installation.*



*Ceramics kiln lined with woven continuous filament ceramic fibre blanket for hot face covering*

### KEY POINTS

- Refractories provide essential high temperature insulation to protect the furnace structure.
- A range of refractory materials are available offering different combinations of properties including:
  - maximum operating temperature;
  - thermal conductivity;
  - erosion resistance;
  - corrosion resistance;
  - coefficient of expansion.
- There is often a trade-off between refractory properties, e.g. those with good insulating properties have relatively poor erosion resistance.
- For this reason, refractories are often layered with a high temperature, erosion resistant refractory being used to face a less robust, but better insulating, inner layer.
- Different areas and zones within a furnace will require different refractory formulations.
- Low thermal mass (LTM) materials, e.g. ceramic fibre, are now available that allow more rapid warm-up/cool-down in intermittent furnaces. This can yield significant production and energy benefits.
- LTM materials have poorer mechanical properties than conventional refractories and hence the latter are often the preferred choice in aggressive environments.

- Monitor refractory condition to determine the optimum time for replacement or repair.
- On continuous furnaces, the condition of internal refractories can be monitored by regularly measuring and recording the external surface temperature of the furnace shell.
- It is possible to carry out in-situ refractory repairs in most furnaces but this is a specialist activity and must be undertaken strictly in accordance with the refractory manufacturer's recommendations.
- Correct installation techniques are essential if refractories are to perform correctly and have maximum longevity.
- Installation procedures must include consideration of drying out and controlled initial warm-up to full operating temperature.
- Never attempt to 'repair' refractory by adding additional insulation to 'hot spots' on the outside of the furnace shell.
- However, external insulation can be applied effectively to lower temperature plant, e.g. recuperators and regenerators.

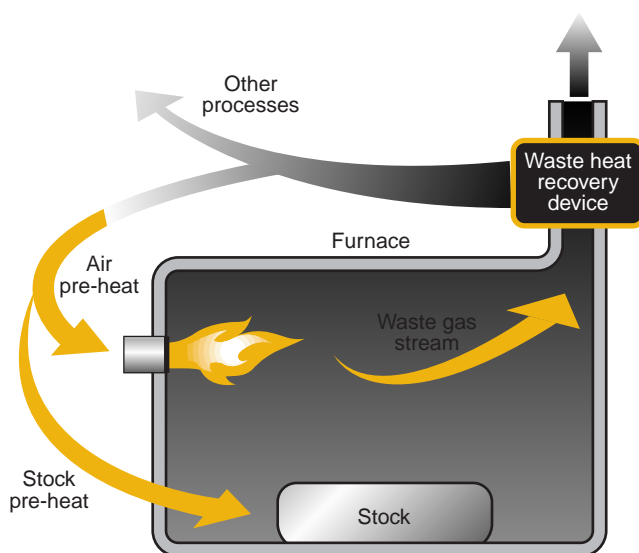
**For further information, refer to the Core Guides (see the fax-back form), plus:**

Non-ferrous metals	GPCS 218	<i>Corundum-resistant furnace lining</i>
Glass	GPCS 133	<i>External spray insulation on furnace regenerators</i>
Ceramics	GPG 244	<i>The use of low thermal mass materials and systems in the ceramic industries</i>

*A large proportion of the energy used by furnaces is lost either in the flue gases or with the hot product. If this heat can be recovered and re-used, then less energy will be required.*

*Waste heat recovery is a widely applicable technique but is not always cost-effective. As with any retrofit modification, the economics of waste heat recovery improve with larger scale and extended hours of use.*

*It follows that waste heat recovery techniques are most applicable to large, continuous furnaces and least applicable to smaller, intermittent ones.*



Recovery of waste heat from a furnace

### KEY POINTS

- It is far better to reduce the quantity of waste heat produced than to recover it. Therefore, ensure that all other aspects of the furnace operation are optimised before considering waste heat recovery.
- Waste heat recovery can be applied to most types of furnace and may lead to higher throughputs as well as energy savings. A variety of techniques are available, these include:
  - flue gas recuperation (Fact File T9);
  - flue gas regeneration (Fact File T11);
  - stock recuperation (Fact File T12).
- The recovery of waste heat from flue gases will reduce gas temperature, which can be useful if subsequent emission abatement processes are required.
- All waste heat recovery schemes require a heat source and a heat sink (recipient). The most effective schemes require these to be matched in terms of:
  - quantities of heat available/required;
  - temperatures available/required;
  - timing of heat availability/requirement;
  - close physical proximity.
- Consider heat recovery to the furnace as first choice, e.g. pre-heating combustion air or feed stock. Be aware, however, that pre-heating combustion air will lead to a higher flame temperature and hence may increase NO<sub>x</sub> emissions.
- Recovered heat can also be transferred for use in other processes, e.g. drying, or to provide space heating.
- Alternatively, waste heat boilers can be used to raise steam for power generation or process use.
- Recover waste heat at as high a temperature as possible to provide best heat exchanger performance.
- When assessing a waste heat recovery scheme always consider:
  - impact on furnace conditions, e.g. back pressure or flame characteristics;
  - potential fouling of heat exchange surfaces;
  - maintenance requirements, e.g. a bypass facility may be required.
- Up to 50% energy savings are possible.
- Typical payback on investment is 2 – 5 years.

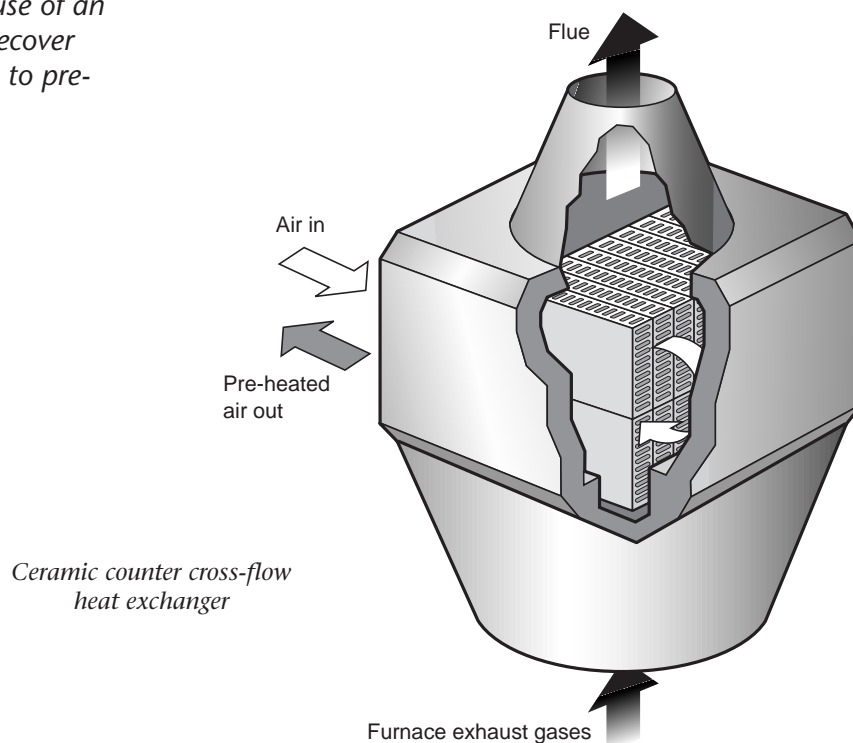
**For further information, refer to the Core Guides (see the fax-back form), plus:**

All sectors

GPG 13

Waste heat recovery from high temperature gas streams

*Recuperation involves the use of an in-line heat exchanger to recover waste heat from flue gases to pre-heat combustion air.*



### KEY POINTS

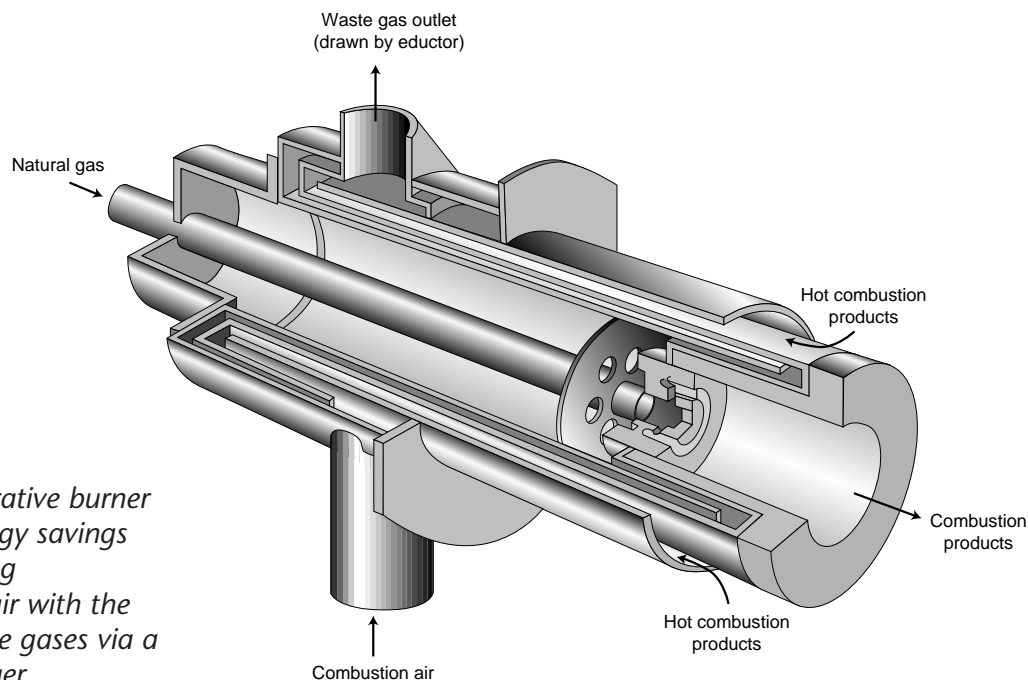
- Pre-heating combustion air is a popular means of waste heat recovery as the characteristics of the heat source and sink are inevitably matched. NO<sub>x</sub> emissions can increase, however.
- Many conventional burners will accept combustion air pre-heated up to 300°C. Above this, special high temperature burners are available.
- A range of heat exchanger types is available made from steel, high temperature alloys or ceramic materials.
- A development of the recuperative principle is the self-recuperative burner (Fact File T10) which incorporates the heat exchanger within the burner itself.
- If flue gases are hotter than 1,000°C, heavily dust-laden or chemically aggressive, then flue gas regeneration (Fact File T11) may be preferable.
- At lower flue gas temperature (below 400°C), plate heat exchangers can effectively generate warm air for other purposes, e.g. space heating or drying, while liquids, e.g. thermal fluid, can be heated using shell and tube heat exchangers.
- The economics of flue gas recuperation generally improves with larger furnaces and longer operating hours.

### Characteristics of heat exchanger types

Type	Temp (°C)	Efficiency	Resistance to fouling
Plate	<800	40 – 60%	Poor
Shell and tube	<550	70 – 90%	Moderate
Radiation recuperator	<1,400	10 – 20%	Good
Convection recuperator	<1,200	30 – 50%	Moderate

**For further information, refer to the Core Guides (see the fax-back form), plus:**

All sectors	GPG 13	Waste heat recovery from high temperature gas streams
Non-ferrous metals	NPP 48	Recuperative aluminium recycling plant



*A self-recuperative burner provides energy savings by pre-heating combustion air with the exhaust waste gases via a heat exchanger incorporated in the burner body.*

*Self-recuperative burner*

### KEY POINTS

- The self-recuperative burner comprises annular chambers. The inner chamber carries the fuel gas, while the middle annular chamber carries the combustion air.
- The fuel gas and combustion air mix and are ignited in the combustion chamber.
- Flame reversal occurs in the furnace and the combustion products flow out of the furnace via the outer annulus, pre-heating the combustion air and fuel gas.
- Self-recuperative burners can be bought off the shelf and are simple to install, particularly for retrofit projects.
- The burners ensure a perfect match between waste heat availability and demand, while their compact design means lower heat losses than some alternative waste heat recovery systems.
- Installation costs are competitive relative to other forms of waste heat recovery, with energy savings of up to 50%.
- Typical payback periods are 2 – 4 years.
- Self recuperative burners are best applied on processes with waste gas temperatures between 800 – 1,500°C and can only be used with clean waste gases.
- In retrofit installations, flame characteristics and the flue gas path will change. This is often advantageous, but temperature distribution problems can sometimes occur. NO<sub>x</sub> emissions can also increase.

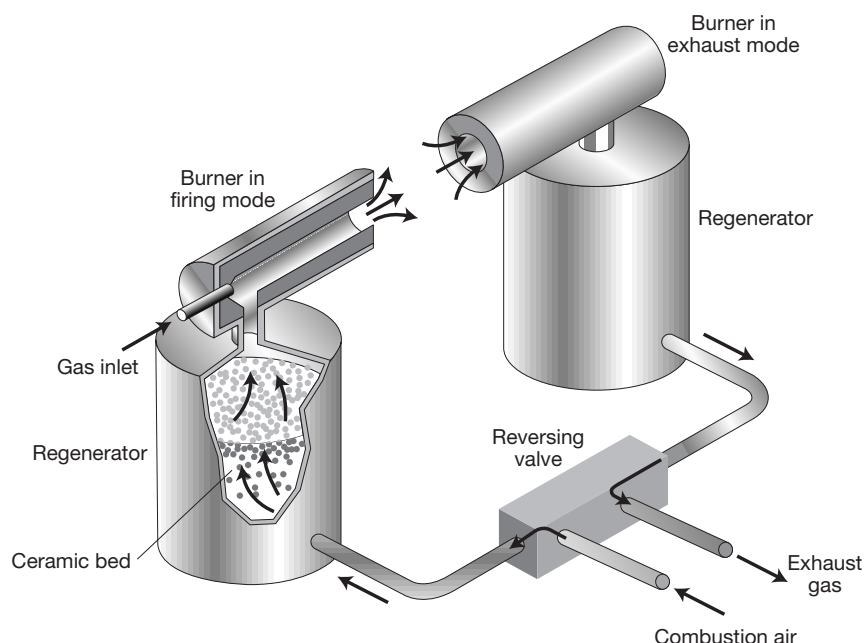
**For further information, refer to the Core Guides (see the fax-back form), plus:**

All sectors

GPG 13

Waste heat recovery from high temperature gas streams

*Regeneration uses a short-term cyclic heat storage device as the means of achieving waste heat recovery.*



*Schematic diagram of regenerative burner firing principle*

### KEY POINTS

- A regenerative system typically comprises a pair of heat-retaining ceramic cores which are alternatively heated (by passing hot flue gases through them), and then cooled (using incoming combustion air), thereby achieving heat transfer.
- Traditional static regenerators are very large (the size of a two storey house) but are robust, corrosion resistant and capable of handling contaminated hot gases. Cycle times are up to 30 minutes.
- Rotary regenerators are smaller and use a constantly rotating ceramic disc as the means of transferring heat between neighbouring flue gas and combustion air ducts.
- Compact ceramic regenerator systems are most widely applicable. These are about the size of a dustbin and can be close-coupled to a high temperature burner. The burner/regenerator units are operated in pairs. Cycle times are typically 60 – 120 seconds.
- Latest developments include a range of compact, self-contained regenerative burners. These are suitable for retrofit applications. Installed in pairs, cycle times can be as short as 15 seconds.
- Regenerative burners are now available in a range of sizes from 65 kW to over 5 MW.

#### Characteristics of regenerator systems

Type	Temp (°C)	Efficiency	Resistance to fouling
Static	1,000 – 1,500	70 – 90%	Good
Rotary	1,000 – 1,700	70 – 90%	Poor
Compact	1,000 – 1,500	70 – 90%	Moderate
Burner	700 – 500	60 – 80%	Poor

**For further information, refer to the Core Guides (see the fax-back form), plus:**

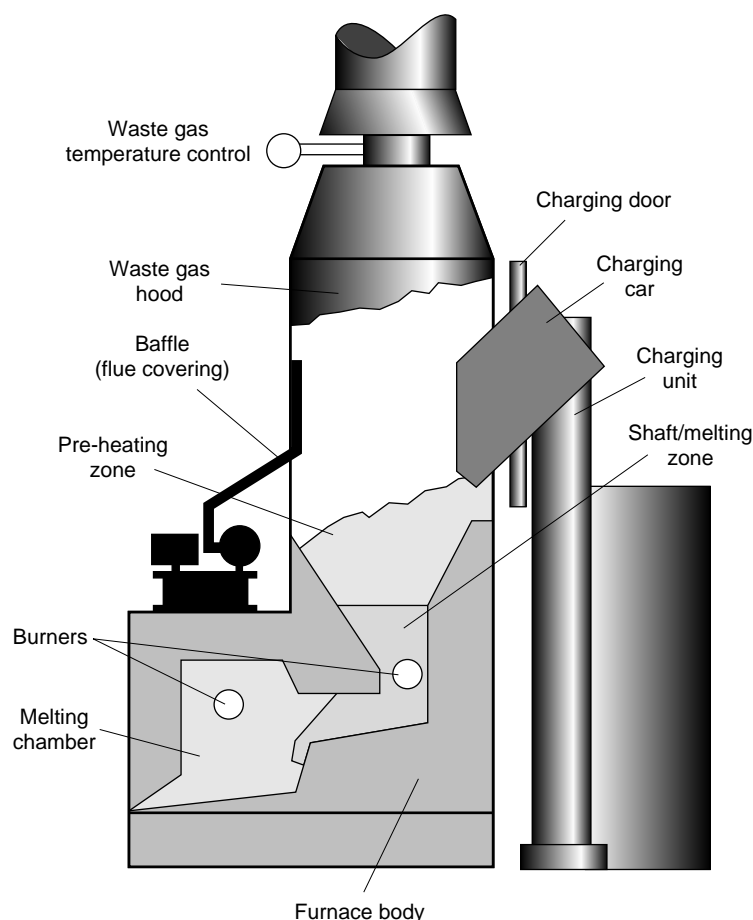
All sectors

GPG 13

Waste heat recovery from high temperature gas streams

*The heat contained within hot product (stock) as it is discharged from a furnace is often wasted. If this heat can be recovered, efficiency will be improved.*

*Similarly, incoming feedstock can be pre-heated using waste heat contained in flue gases etc. as a useful means of heat recovery.*



### KEY POINTS

- Heat is most often recovered from hot product by cooling it with air.
- The resulting warm air can then be used as combustion air or for other processes, e.g. drying.
- Feedstock pre-heating is most easily applied to continuous furnaces as there are no problems in matching the timing of heat availability and demand.
- Feedstock pre-heating can also be applied to intermittent furnaces, particularly if there are a number of them and their warm-up/cool down cycles can be sequenced to overlap.
- The output of many furnaces will go to further processes that require hot feed stock. Under these circumstances, it is usually better to ensure that the heat is retained within the stock, rather than trying to remove it for recovery.
- Heat can be retained in hot product by:
  - minimising transportation distance between the furnace and the downstream process;
  - minimising transport times;
  - providing insulated transport routes.

**For further information, refer to the Core Guides (see the fax-back form), plus:**

All sectors

GPG 13

Waste heat recovery from high temperature gas streams

Non-ferrous metals

GPCS 112

Gas-fired shaft furnaces

*Over their operating life, electric motors can consume electricity worth 100 times the purchase price of the motor itself. It follows that efforts aimed at improving the efficiency of electric motors (and the systems they power) will be well rewarded.*

*There are three basic options for reducing the energy consumption of a motor:*

- **switch it off when not needed;**
- **select the right one;**
- **slow it down.**



*Laminar cooler supply pumps and new motors*

### KEY POINTS

#### Switch It Off When Not Needed

- Turn off motors when not required, e.g. on empty conveyors. Consider simple electrical interlocks to achieve this automatically.

#### Selecting the Right Motor

- Specify 'higher efficiency motors' for all new purchases (available from major manufacturers at little or no extra cost).
- Consider replacing rather than repairing failed electric motors.

#### Slowing It Down

- If dampers are currently used for adjusting air flow, consider using a variable speed drive (VSD) instead. The power cube rule means that just reducing the speed by 20% can reduce the power consumption by up to 50%.
- The economics of installing a VSD are influenced by:
  - the size of the load relative to motor rating (the smaller the load the better);
  - the size of motor (the bigger the better);
  - the operating hours (the longer the better);
  - the variability of the load (the more variable the better).
- Similar savings can be made by replacing throttle control with VSDs on centrifugal pumping systems.

**For further information, refer to the Core Guides (see the fax-back form), plus:**

All sectors	GPG 2	<i>Energy savings with electric motor and drives</i>
	GPCS 222	<i>Purchasing policy for higher efficiency motors</i>
	GIL 56	<i>Energy savings from motor management policies</i>
Ferrous metals	GPCS 125	<i>Variable speed drives on a batch furnace combustion air fan</i>
	GPCS 356	<i>Conflict control of a combustion air fan on a large continuous furnace</i>
	GPCS 162	<i>High efficiency motors on fans and pumps</i>

*Following initial efforts to improve the energy efficiency of the furnace itself, as the major energy user, it is worth investigating the savings available from reviewing the operation of ancillary services, such as compressed air and cooling water services. Very often these are taken for granted and receive little attention until they go wrong.*

*Savings are available from a combination of good housekeeping measures, e.g. the rapid repair of compressed air leaks, and capital expenditure on system modifications such as improved controls and variable speed drives.*

### KEY POINTS

#### Compressed Air

- Compressed air typically costs ten times as much as electricity.
- Carry out regular leak tests, adopt a system of leak tagging and repair leaks promptly.
- Do not generate air at a higher pressure than you need. Question the need to generate at a pressure above 7 bar (gauge).
- Ensure compressor rooms are well-ventilated, as compressor efficiency deteriorates as air inlet temperature increases.
- Sequence control compressor capacity in line with air demand, and ensure the load compressor has automatic capacity regulation to allow the quantity of air delivered to match demand precisely.
- Maintain compressors regularly (particularly air inlet filters).
- Consider waste heat recovery, to generate hot water and/or warm air, e.g. for factory heating.

#### Cooling Water

- Fit point-of-use controls to minimise water consumption.
- Use re-circulatory systems, e.g. with cooling towers, rather than running mains water to drain.
- Position cooling towers to ensure a free circulation of air.
- Pumps and fans should use energy efficient motors (Fact File T13).
- Control pumps and fans in line with cooling demand. For example, use thermostatic sequence control or variable speed drives (Fact File T13).
- If multiple cooling pumps are installed in parallel, make sure the non-return valves are fitted to prevent water short-circuiting back through off-line pumps and check annually that they are still sealing properly.
- Adopt rigorous water treatment regimes to maintain system performance and eliminate potential health/hygiene issues, e.g. Legionella pneumophylla.
- In larger, continuous cooling water applications, consider the use of low-friction polymer coatings to reduce friction losses on pump internal surfaces.

#### For further information, refer to the Core Guides (see the fax-back form), plus:

All sectors	GPG 225	<i>Industrial cooling water systems</i>
	GPG 126	<i>Compressing air costs</i>
Ferrous metals	GPG 170	<i>Reducing water pumping costs in the steel industry</i>
Glass	GPCS 251	<i>An energy management and investment campaign at a glass plant</i>

## **APPENDIX 1**

### **GLOSSARY**

Break clause	A clause in longer term gas or electricity supply contracts which allows the customer to seek alternative quotations at each renewal anniversary. The supplier undertakes to match the best price received or release the customer from the contract.
Burner quarls	Refractory components surrounding the burner nozzle.
Calorific value (CV)	The heat liberated by the complete combustion of a unit quantity of fuel. The gross calorific value is the total heat available after the water formed as a combustion product has condensed. The net calorific value signifies that the water formed is still a vapour.
Combustion air	The air supplied through a burner other than that supplied for the atomisation of fuel oils.
Combustion efficiency	The proportion of the energy in the fuel (based on its calorific value) used to satisfy all the heating requirements and energy losses associated with the furnace excluding the heat content of the exhaust gases. It is usually expressed as a percentage.
Continuous furnaces/kilns	Typically these are 'tunnel' furnaces or kilns with the stock passing through them on a continuous basis.
Convection	Transfer of heat by the bulk movement of a hot fluid, e.g. air, from one place to another.
COP meter	An electronic electricity meter which is required if competitive electricity supply contracts are to be sought. The meter can be read remotely by modem and conforms to an approved Code of Practice (COP).
Correction capacitors	Electrical capacitors which are installed, adjacent to either large plant or distribution boards, to improve the power factor.
Direct firing	Firing without protecting the ware from the products of combustion.
Dual-fuel burners	Burners equipped to fire more than one fuel e.g. gas or oil.
Excess air	Air supplied in addition to that required for the stoichiometric combustion of a fuel.
Fouling	A term used for the deposition of oxides or other process derived emissions on the heat exchange surfaces in waste heat recovery systems.
Furnace scheduling	Refers to the management of processes to ensure the minimum waste of energy/loss of product.
Furnace yield	Tonnage of product from furnace per tonne of feedstock.

Higher efficiency electric motors	Higher efficiency motors are manufactured to improved design standards employing more copper and iron. This means that the motor's conversion of input electrical power (kW) to output power is improved by typically 3 – 6%, depending on motor sizing.
Heat work	A mathematical concept used to understand furnace performance. It is a function of the temperature to which stock is heated and the length of time that it is held at that temperature.
Hot inspection	A term used in the glass industry but is applied in the metal industries. The technique of inspection soon after the products are made rather than waiting for them to cool, thereby avoiding the possibility of more scrap being made in the meantime.
Hysteresis	Lag or 'slack' within a control system that leads to inconsistent performance.
Indirect firing	Applied to the ferrous, non-ferrous and ceramics industries where the product is protected from direct flame impingement from the burners by refractory or metallic baffles, for example muffle furnaces.
Induction furnaces	These are used only for metals. Typically, a high frequency electrical current is passed through a copper coil surrounding the product. This induces currents within the product whose electrical resistance causes the product to heat up.
Intermittent furnaces/kilns	A general term applied to batch furnaces/kilns in the ferrous, non-ferrous and ceramic industries.
Light up	The period when the furnace temperature is being raised in preparation for production, e.g. following a period when the burners have been turned off.
Liquefied petroleum gas (LPG)	Usually propane, butane or a mixture of both.
Low thermal mass (LTM)	Refractory materials having low bulk density and low specific heat.
MPAN	Metering Point Administration Number - a series of numbers contained within a grid printed on all electricity bills which is unique to you as a customer. It provides essential infrastructure information to allow potential suppliers to provide you with a competitive quotation.
Muffle	A refractory lining to a kiln or furnace that prevents the stock from coming into contact with combustion gases.
Oxygen enrichment	The practice of adding oxygen to combustion air to increase its oxygen content. Typically between the normal atmospheric ratio (21%) and 26%.
PID	Proportional Integral Derivative – a widely used control algorithm which allows close control with minimal overshoot.

Plate heat exchanger	A heat exchanger in which thin corrugated plates are fixed together to form a compact unit with hot and cold fluid flowing along adjacent passages.
Power factor	An electrical term. A measure of the 'effectiveness' of electrical supplies. A poor power factor may increase the cost of electricity.
Products of combustion	The materials remaining after combustion of a fuel. Generally include CO <sub>2</sub> , H <sub>2</sub> O, and N <sub>2</sub> but may also include CO, H <sub>2</sub> , O <sub>2</sub> , aldehydes and other complex hydrocarbons, sulphur compounds, N <sub>2</sub> compounds and particulates.
Radiation	Transfer of heat by the electromagnetic waves, e.g. infrared radiation, given off by a hot body.
Refractories	A general term applied to the ceramic structures lining the hot face of a furnace chamber.
Regenerative furnace	A furnace in which the hot gases pass through chambers containing fire-brick structures, to which the sensible heat is given up. The direction of gas flow is reversed periodically and cold incoming gas is pre-heated in the chambers.
Scrubbers	Pollution abatement equipment used to remove particulate or other contaminants from a gas stream.
Self-recuperative burner	A burner in which waste gases are used to pre-heat the combustion air to that burner.
Specific energy consumption	The amount of energy used to process a unit (usually one tonne) of stock.
Specific heat	The quantity of heat required to raise the temperature of a unit mass of a substance by one degree.
Star/delta	Alternative arrangements for connecting the windings on electric motors to the individual phases of a 3-phase supply.
Stratification	The establishment, within a furnace, of a horizontal laminar flow of the atmosphere with a stable vertical temperature gradient.
Stock recuperation	A technique whereby the exhaust gases leave the furnace at the charge end, thus enabling their waste energy to pre-heat the stock.
Supply capacity (or availability)	The maximum rate (expressed in kW or kVA), at which a customer is allowed to consume electricity. This figure is contractually agreed with the local electricity company and is charged for, each month, on the bill.
Thermal conductivity	The physical property of a material that describes the rate of flow of heat through a unit surface area of a material. The SI unit is Watts per metre per degree Kelvin (W m <sup>-1</sup> K <sup>-1</sup> ).
Thermocouples	Device for measuring temperature on the basis of the electrical current generated by the junction between two dissimilar conductors on heating.

**APPENDIX 2****LITERATURE REQUEST FORM**

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To receive your free copies of the listed publications, photocopy this form and fill in the company details below, tick your requirements and fax to the number above or post to: Energy Efficiency Enquiries Bureau, ETSU, Building 168, Harwell, Didcot, Oxfordshire OX11 0QJ.

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Ref	Title	Tick
<b>CORE GOOD PRACTICE GUIDES</b>		
GPG 50	Efficient operation of coreless induction furnaces	
GPG 58	Cupola melting of cast iron in iron foundries	
GPG 76	Continuous steel reheating furnaces: specification, design and equipment	
GPG 77	Continuous steel reheating furnaces: operation and maintenance	
GPG 127	Energy efficient environment control in the glass industry	
GPG 164	Energy efficient operation of kilns in the ceramic industries	
GPG 252	Burners and their controls	
<b>OTHER GOOD PRACTICE GUIDES</b>		
GPG 2	Energy savings with electric motors and drives	
GPG 13	Waste heat recovery from high temperature gas streams	
GPG 14	Retrofitting AC variable speed drives	
GPG 17	Achieving high yields in iron foundries	
GPG 63	Metal distribution and handling in iron foundries	
GPG 68	Electric holding of hot metal in iron foundries	
GPG 69	Investment appraisal for industrial energy efficiency	
GPG 126	Compressing air costs	
GPG 142	Improving metal utilisation in aluminium foundries	
GPG 170	Reducing water pumping costs in the steel industry	
GPG 225	Industrial cooling water systems	
GPG 230	Implementation of hot linking	
GPG 244	The use of low thermal mass materials and systems in the ceramic industries	
<b>GENERAL INFORMATION LEAFLETS</b>		
GIL 56	Energy savings from motor management policies	

Ref	Title	Tick
<b>GOOD PRACTICE CASE STUDIES</b>		
GPCS 36	Computer simulation of solidification in non-ferrous sand foundries	
GPCS 37	Computer simulation of solidification in ferrous foundries	
GPCS 112	Gas fired shaft furnaces	
GPCS 125	Variable speed drives on a batch furnace combustion air fan	
GPCS 133	External spray insulation on furnace regenerators	
GPCS 135	Furnace scheduling advisory system	
GPCS 160	Expert system improves performance of plc control plant	
GPCS 161	Cupola melting of cast iron	
GPCS 162	High efficiency motors on fans and pumps	
GPCS 183	Performance monitoring of a re-heat furnace	
GPCS 213	Demonstrating good practice in medium frequency coreless induction furnaces	
GPCS 218	Corundum-resistant furnace lining	
GPCS 222	Purchasing policy for higher efficiency motors	
GPCS 251	An energy management and investment campaign at a glass plant	
GPCS 263	Hot charging practice for continuous steel reheating furnaces	
GPCS 267	Permanent star running of a lightly loaded motor	
GPCS 282	Use of molten metal filters in non-ferrous foundries	
GPCS 321	Energy monitoring on large steel reheating furnaces	
GPCS 344	Energy savings from small, efficient melting and holding furnaces	
GPCS 345	Energy management techniques in the pottery industry	
GPCS 353	The use of filters in ferrous foundries	
GPCS 356	Conflict control of a combustion air fan on a large continuous furnace	
GPCS 371	New glass furnace with energy efficiency features and improved insulation	
<b>NEW PRACTICE PROFILES AND NEW PRACTICE CASE STUDIES</b>		
NPP 10	Computer controlled furnace management	
NPP 32	Fast firing of decorated ceramic ware	
NPP 48	Recuperative aluminium recycling plant	
NPP 54	Dual fuel regenerative burners	
NPCS 89	Energy efficiency training through continuing professional development	
<b>FUTURE PRACTICE PROFILES</b>		
FPP 33	Reduction of costs using an advanced energy management system	
FPP 47	Quantifying important factors in iron melting in medium frequency coreless induction furnaces	
<b>ENERGY CONSUMPTION GUIDES</b>		
ECG 27	The glass container industry	
ECG 38	Non ferrous foundry industry	
ECG 43	The UK non-fletton brickmaking industry	
ECG 48	UK iron foundry industry	
ECG 61	Energy consumption in the ceramics industry	
ECG 63	Energy consumption in the manufacture of domestic, borosilicate and specialist glass	

**The Government's Energy Efficiency Best Practice Programme** provides impartial, authoritative information on energy efficiency techniques and technologies in industry, transport and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice Programme are shown opposite.

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**Future Practice:** reports on joint R & D ventures into new energy efficiency measures.

**General Information:** describes concepts and approaches yet to be fully established as good practice.

**Fuel Efficiency Booklets:** give detailed information on specific technologies and techniques.

**Energy Efficiency in Buildings:** helps new energy managers understand the use and costs of heating, lighting etc.

